SF Environment

Plastic Pipe Alternatives Assessment

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Executive Summary

Plastic pipe is increasingly being used in place of traditional materials (copper, steel, concrete, vitrified clay) in a variety of applications. Lower material cost, ease of installation, resistance to chemicals, resilience and durability are key characteristics that have made plastic pipe popular. However, increasing concerns have been raised in recent years about the environmental profile of plastic pipe. Particular concern has been raised about the chemicals used in plastic pipe production and otherwise associated with the life cycle of these pipes. While sharing a common origin in fossil fuels, each of the different plastics used in pipes is manufactured through different procedures and contains different chemicals with unique environmental characteristics. This report was commissioned by the City of San Francisco to identify key attributes of the different plastic pipe types to assist the City in aligning its pipe purchasing policies with its chemical and other environmental concern policies.

This study seeks to answer the question of whether there are significant differences between the plastics used to manufacture pipes with a focus on priority environmental health impacts and end of life recyclability. No determination is made on whether plastics are either more or less preferable to the traditional materials used to manufacture pipes. Rather the evaluation is for decision-makers interested in understanding the environmental differences between plastics.

In this report, the plastics used to manufacture pipes are analyzed and compared for **chemical hazards**, **recyclability** and **performance**. The chemical hazard and recyclability assessments evaluate the environmental sustainability of plastics, while the performance assessment gauges the technical, market, and economic viability of the materials in different applications.

Five plastics commonly used in pipes are evaluated:

- Acrylonitrile butadiene styrene (ABS)
- High density polyethylene (HDPE)
- Cross-linked polyethylene (PEX)
- Polypropylene (PP)
- Polyvinyl chloride (PVC and CPVC[1])

The emphasis of the hazard assessment method used in this report is to **prevent pollution at the source** by avoiding materials and processes that use or generate priority hazardous chemicals. Rather than attempting to determine the quantity of all chemicals generated as pollution and minimizing the volume of those discharges, this hazard assessment method guides decision-makers to materials that are less hazardous across their life cycle by **prioritizing the avoidance of chemicals that are chronic human health hazards, persistent, or bioaccumulative.**

The **chemical hazards** examined when analyzing the life cycle of these materials include: carcinogenicity, mutagenicity, reproductive toxicity, endocrine disruption, persistence, and bioaccumulative capacity.[2] **Priority Chemicals** in this study are hazardous chemicals that have been targeted for reduction or elimination on a select set of US and international governmental lists.[3] In this analysis, therefore, a preferable plastic is one that does not use as input or generate as output a chemical on the referenced governmental chemical hazard lists and that is truly closed loop recyclable with a strong infrastructure to facilitate that recycling.

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[1] CPVC – chlorinated polyvinyl chloride. A modified form of polyvinyl chloride that has more chlorine atoms per repeating monomer unit than does the polyvinyl chloride molecule. This extra chlorine gives CPVC strength at higher temperatures than PVC.

[2] This report does not examine all the potential hazards – including ergonomics, flammability, corrosivity, and neurotoxicity – associated with a chemical.

[3] **Priority Chemicals of Highest Concern** for this study are those in the Stockholm Convention on Persistent Organic Pollutants, Priority Persistent Bioaccumulative Toxic (PBT) Pollutants and Priority Chemicals lists by the US Environmental Protection Agency (USEPA) and Chemicals for Priority Action by the Oslo-Paris Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR).

The analysis of the existing data leads to four primary conclusions:

- HDPE and PP are the most environmentally preferable plastics currently used to manufacture pipes under this chemical hazard and recyclability based analysis with no significant distinction between them. Yet even these plastics have their environmental downsides.
- HDPE, PP, and PEX create fewer chemical hazards of high concern across their life cycles than ABS and PVC.
- Plastic pipes are currently seldom recycled. Yet of the plastics used to manufacture pipes, a few general trends emerged. HDPE and PP are the most recyclable and recycled of the plastics (used in pipes). While ABS is recyclable, the recycling markets are small. PEX is inherently difficult to recycle. Finally, while PVC is recyclable under some circumstances, it is considered a contaminant in many recycling programs and its use is increasingly avoided in the automotive sector.
- Plastic pipe alternatives exist in the Prefer category in this analysis (HDPE and PP) that perform equal to or better than the plastics in the Avoid and Concern categories (PVC, ABS and PEX) for each of the pipe applications studied. Availability of preferable alternatives is good in North American markets with the exception of drain-waste-vent (DWV) applications The entry of new PP and HDPE products, with encouragement from forward looking environmentally preferable purchasing policies, is expected to expand availability of preferable alternative options in the North American market for all applications, including DWV.

All the plastic materials examined here have a common raw material origin in crude oil and natural gas. The extraction and refining of oil and gas generate Priority Chemical byproducts. All the plastics examined here, therefore, share a common set of chemical hazards from these processes.

PVC is slightly different than the other plastics because 57% of the weight of raw PVC resin (before additives) is from chlorine manufactured from brine (salt water) instead of from petrochemicals. Chlorine manufacture, however, also creates a similar set of Priority Chemical byproducts. Neither chlorine manufacturing nor oil and gas refining is a more environmentally preferable production system. Therefore the environmental differences between plastics emerge most significantly after the raw material extraction and refining stages. In this analysis, ABS and PVC stand out for their unique association with Priority Chemicals of Highest Concern throughout the rest of their life cycles.

PVC is the only plastic examined in this report to have persistent organic pollutants (POPs) targeted for elimination by the Stockholm Convention throughout its life cycle – that is, after the extraction and refining stages that all plastics share. Throughout the manufacture of PVC, dioxins, furans, hexachlorobenzene, and PCBs continue to be unavoidably produced, primarily because of its chlorine content.

Dioxins are further associated with the combustion of PVC products both during the use phase in accidental building and vehicle fires and at the end of life in incineration and landfill fires.

The unique toxicity of these chemicals, along with their persistent and bioaccumulative nature, has made them a top international priority for elimination[4] . PVC is also the only plastic examined here to have OSPAR Chemicals for Priority Action (organotins, lead, and possibly cadmium) in the final product itself.

Both ABS and PVC differ from the other plastics in their use of carcinogens[5], mutagens, reproductive/developmental toxicants, and endocrine disruptors, either as inputs into the manufacturing process and/or as inputs into the final product.[6]

Recyclability is evaluated primarily on indicators from current recycling markets and evaluations from parallel industries utilizing these plastics. Little recycling is being done with any plastic pipes. All of the plastics are theoretically recyclable and token plastic pipe recycling programs exist for each[7]. However there are significant moves away from PVC, because it is difficult to recycle, and toward the polyolefins

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[4] Stockholm encourages product substitution as a method to eliminate these chemicals, reinforcing the importance of prevention through establishing preferences rather than through risk assessment based pollution management.
[5] All of the polymers do use one carcinogen - carbon black - for pipes that may be exposed to UV (ultraviolet) light.
[6] Note that the analysis is limited to the chemical class level for many of the additives used to manufacture plastic pipes as the specific chemical data is considered proprietary by manufacturers.
[7] Although for PEX the only known programs are waste to energy conversion, not true recycling.

(HDPE and PP), with ABS somewhere in the middle. The data indicate that the markets for recycling HDPE and PP will be more robust than PVC and PEX in the future with ABS less certain.

Performance is evaluated on installation, cost, availability and chemical resistance, durability, life span and other related issues. Use of PEX is restricted to relatively small diameter indoor water distribution applications and ABS is generally only used for DWV applications. PVC, PP and·HDPE all perform satisfactorily in all applications. Availability is good for all types except for PP in North America.

Table 1 summarizes the results of the analysis and the conclusions of this report.

The hazard and recycling assessments clearly indicate that HDPE and PP are more environmentally preferable than PVC. ABS and PEX occupy a middle ground of concern between PVC at least preferable and HDPE / PP at most preferable. ABS is in the middle ground because of its better recycling profile than PVC. While PEX is preferable to ABS and PVC on chemical hazards, questions remain about its recyclability.

Performance characteristics are generally not an obstacle to using at least one of the polyolefins (HDPE, PP or PEX) to replace the PVC and ABS materials in each application and market availability is growing in all areas. DWV is the only area with market availability obstacles significant enough to slow down replacement at this time.

Table 1. Summary of Plastic Pipe Environmental Preferability Analysis						
	Avoid	Concern		Prefer		
	PVC	ABS	PEX	PP	HDPE	Preferable
Summary of chemical hazard & recyclability assessments	·worst chemical hazard ·poor recyclability	·more chemical hazard ·low recycling	·less chemical hazard ·very limited recyclability	·less chemical hazard ·good recyclability	·less chemical hazard ·good recyclability	Truly preferable plastic pipes do not yet exist
--- Chemical Hazard Assessment ----------						
Stockholm POPs (outputs after refining)	Dioxins, Furans, Hexachloro-benzene, PCB	+ none	+ none	+ none	+ none	
OSPAR & USEPA PBT & Priority Chemical (inputs)	Cadmium, Lead, Organotins,	+ none	+ none	+ none	+ none	
Chronic toxicants; Carcinogens, mutagens, developmental or reproductive toxicants or endocrine disruptor (inputs)	Cadmium, Carbon black, EDC, Lead compounds, Organotins, VCM	1,3-Butadiene, Acrylonitrile, Benzene, Carbon black, Ethyl-benzene, Styrene	Carbon black	Carbon black	Carbon black	
Other PBT Outputs	many	many	many	many	many	
--- Recyclability Assessment----------						
Summary recycling markets and recyclability assessment	Little recycling. Considered a contaminant to municipal recycling	Recyclable but small markets	Very limited. Only recycled as filler in other products. Can never be closed loop recycled.	+ Established post consumer recycling markets (automotive)	+ Established post consumer recycling markets (bottles)	
--- Performance / Availability Assessment----------						
- Water distribution	Good/Good	Not used/NA	Good/Good*	Good/Poor*	Good/Good*	
- Drain/Waste/Vent	Good/Good	Good/Good	Not used/NA	Good/Poor	Not used/NA	
- Sanitary sewer	Good/Good	Not used/NA	Not used/NA	Good/Poor	Good/Good	
- Storm sewer	Good/Good	Not used/NA	Not used/NA	Good/None	Good/Good	
- Irrigation & drainage	Good/Good	Not used/NA	Not used/NA	Good/None	Good/Good	
- Irrigation & drainage	Good/Good	Not used/NA	Not used/NA	Good/Poor	Good/Good	
*PEX is used only in small diameter piping primarily for water distribution and radiant systems in buildings. HDPE for water distribution is used primarily in larger diameter piping outside the building. PP is just beginning to be marketed in North America						

Introduction

Plastic pipe is increasingly being used in place of traditional materials (copper, steel, concrete, vitrified clay) in a variety of applications. Lower material cost, ease of installation, resistance to chemicals, resilience and durability are key characteristics that have made plastic pipe popular. However, increasing concerns have been raised in recent years about the environmental profile of plastic pipe. Particular concern has been raised about the chemicals used in plastic pipe production and otherwise associated with the life cycle of these pipes. While sharing a common origin in fossil fuels, each of the different plastic pipe polymers is manufactured through different procedures and contains different chemicals with unique environmental characteristics. This report was commissioned by the City of San Francisco to identify key attributes of the different plastic pipe polymers to assist the City in aligning its pipe purchasing policies with its chemical and other environmental concern policies.

This report surveys currently available data about chemicals associated with the life cycle of five major polymers commonly used in plastic pipes (ABS, HDPE, PEX, PP, and PVC). It assesses each polymer type by the characteristics of chemicals associated with it - such as persistence, bioaccumulation, carcinogenicity and reproductive toxicity - and whether any of those chemicals have been identified on a select set of national and international governmental lists as key chemicals of policy concern. The report also briefly looks at end of life options for recycling of the different pipe polymers. Then performance of each of the plastics pipe polymers is evaluated for a variety of primary uses.

The report concludes with recommendations for pipe polymers to avoid based upon particularly poor environmental profiles where alternatives exist that perform at least equally well.

Assessment protocol

The five plastic pipe polymers compared are:
- Acrylonitrile butadiene styrene (ABS)
- High density polyethylene (HDPE)
- Cross-linked polyethylene (PEX)
- Polypropylene (PP)
- Polyvinyl chloride (PVC, CPVC[8])

The applications assessed are:
- Water distribution
- Drain Waste and Vent (DWV)
- Sanitary Sewer
- Storm Sewer
- Irrigation and Drainage
- Duct and conduit

The analyses of hazards, recyclability, and performance are designed to assist the City in aligning its pipe purchasing policy with four key City values:

- **Reducing chemical hazards:** The City has taken a series of measures to reduce the toxic hazards associated with its operations in the City and in the larger environment beyond the City limits. Particularly relevant to this analysis is the City and County Commission on the Environment's Dioxin Resolution (No. 021-098-COE), which resolved to designate dioxin pollution as a high priority for elimination. This report identifies the key environmental health concerns associated with the chemicals used and released in the life cycle of each pipe material.
- **Precautionary principle:** The City of San Francisco has committed to identifying areas of its purchasing policy that impact issues where threats of serious or irreversible damage to people or natural systems exist. Plastic pipes have been identified as one of those areas due to the chemical releases associated with polymer manufacture, use and disposal. This report provides the careful analysis of alternative plastic pipes that the precautionary principle requires, using the

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[8] The closely related chlorinated polyvinyl chloride or CPVC, used for higher temperature water delivery pipes, is considered a variant of PVC and not separately treated for this analysis.

best science available to help the City select materials that present the least potential threat to human health and natural systems across their life cycle[9].

- **Zero waste:** The assessment evaluates recyclability for each of the materials to help the City move toward its goal of realizing a zero waste materials stream.
- **High performance:** The assessment identifies relative performance issues for each plastic pipe polymer to assist the City in assuring that it uses materials that will perform well, be durable, cost effective and last in their application.

The final summary evaluation is a qualitative analysis based upon absolute screening criteria, not a quantitative impact analysis.

The resulting evaluation:

- **Characterizes chemical hazards** across the life cycle of pipes. The goal is to eliminate the use of plastics that contribute to key environmental health concerns. This is assessed by screening the life cycle of the target plastic polymers and their additives for the use or generation of chemicals listed in the Stockholm POPs and OSPAR agreements and identified on US EPA, California Proposition 65, and other key governmental lists. The plastics are then categorized into a hierarchy of concern based upon this hazard screening.

- **Characterizes recycling** options at the end of life, looking at both current recycling rates and potential recyclability, including compatibility with other recycling streams. The plastics are categorized for preferability in this area with the goal to maximize potential for reuse and recycling and minimize waste.

- **Creates a hierarchy** of plastic pipe types, bringing together the results of the screening criteria applied to these chemical hazard and recyclability profiles. Pipe types are clustered into Avoid, Concern and Prefer categories. In this analysis, the ideal preferable plastic is one that does not use as input or generate as output a chemical identified on the referenced governmental priority chemical lists and that is truly closed loop recyclable with a strong infrastructure to facilitate that recycling.

- **Summarizes** the applicable **performance** characteristics for each pipe type and addresses how they apply to different typical applications.

- **Assesses performance** in each pipe application category to determine if pipes made from polymers which rate better on the chemical hazard and recyclability screening can be substituted for the polymer types identified for avoidance.

Hazard Assessment

Introduction

The assessment focuses on the life cycles of the pipe products from organic chemical production to end-of-life disposal[10]. This is a qualitative life cycle hazard assessment[11] which identifies the use and generation of toxic, persistent, or bioaccumulative chemicals associated with each material. Because the purpose of this assessment is to be used as a guide for **preventive and precautionary action**, the assessment is based upon identifying the presence rather than volume of toxic, persistent, or bioaccumulative chemicals in the material's life cycle. The primacy of **pollution prevention** as the method for managing toxic chemicals was established by the Pollution Prevention Act of 1990:

> The Congress hereby declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled

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[9] For more discussion of the precautionary principle, see Appendix 1

[10] The reasons for separate handling of the initial stages of raw materials extraction and processing are explained later in the text under *Inventorying Inputs and Outputs in the Life Cycles of the Plastics*.

[11] For further discussion of the difference between a life cycle hazard assessment and other forms of life cycle assessments (LCA) see Appendix 1

should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

The emphasis of the analytic method used in this report is to **prevent pollution at the source**, avoiding materials and processes that use or generate the most hazardous chemicals. Rather than attempting to determine the quantity of all chemicals generated as pollution and minimizing the volume of those discharges through end-of-pipe treatment, **this assessment method guides decision-makers to deal with pollution problems through substitution with materials that use and generate as byproduct across their life cycle, chemicals that are less hazardous -- prioritizing the avoidance of chronic human health toxicants, persistent chemicals, or bioaccumulative chemicals.**[12]

To achieve this goal we:

1. Inventory:
- *Inputs*: the chemicals that are used as feedstocks or intermediaries in production of each of the products and
- *Outputs*: those chemicals that are byproducts from the production, use, or disposal of the material.

2. Compare:

- chemical inputs and outputs against a set of Priority Chemicals of Highest Concern, primarily persistent bioaccumulative toxic (PBT) chemicals, targeted by national and international governmental agreements for elimination (see lists below) and

- chemical inputs against governmental chronic toxicant lists (carcinogens, mutagens, reproductive toxicants, and endocrine disruptors) and very persistent or very bioaccumulative chemicals.

3. Prioritize:

- Order plastic pipe materials on the basis of avoidance of key chemicals of concern from each list.

Priority Chemicals of Highest Concern

This assessment first identifies Priority Chemicals of Highest Concern based upon the following four lists of chemicals identified and prioritized for reduction by government bodies due their potential to damage human and environmental health:

- **Stockholm Convention on Persistent Organic Pollutants** (POPs)[13], which is a short list of very persistent, bioaccumulative, and toxic organic chemicals targeted for phase-out by international agreement. The U.S. Government has signed, but not ratified, the Stockholm Convention.
- The **US Environmental Protection Agency's Priority (EPA's) Persistent and Bioaccumulative Toxic (PBT) Chemicals**[14]. PBTs that have been identified by the EPA for national action plans.
- **Oslo-Paris Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR) List of Chemicals for Priority Action** [15] managed by the European Commission. Chemicals on the OSPAR list are of high concern for water toxicity.
- The **US EPA Priority Chemicals**[16] list targeted for reduction in products and wastes in its National Partnership for Environmental Priorities (NPEP).

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[12] For further discussion of the issues behind the choice of precaution, pollution prevention and hazard assessment versus risk assessment or life cycle assessment (LCA) see Appendix 1.

[13] The text of the Stockholm Convention can be found at: http://www.pops.int/documents/convtext/convtext_en.pdf

[14] The list of priority PBT chemicals for which the USEPA is developing national action plans can be found at: http://www.epa.gov/opptintr/pbt/

[15] The list of chemicals identified by the OSPAR Commission for priority action can be found at: http://www.ospar.org/eng/html/

[16] The USEPA NPEP list can be found at: http://www.epa.gov/epaoswer/hazwaste/minimize/chemlist.htm

The chemicals associated with each list are identified in Appendix 2.

Chronic Toxicants as well as Very Persistent & Very Bioaccumulative Chemicals

Chronic toxicants in this assessment refer to chemicals associated with long-term chronic health effects or effects at sub-acute exposures. This assessment is based upon chronic toxicants and very persistent and/or bioaccumulative chemicals listed on the following already scientifically established lists:

Carcinogens are any chemical listed as such by the:

- International Agency for Research on Cancer (IARC)[17]
- U.S. National Toxicology Program[18]
- European Union in Consolidated List Directive 76/769/EEC [19]
- California Office of Environmental Health Hazard Assessment (OEHHA) for Proposition 65[20]

Mutagens, which can cause inheritable genetic damage, are any chemical listed by the European Union as a Category 1 or 2 mutagen in EU Consolidated List Directive 76/769/EEC[21].

Reproductive or developmental toxicants are any chemical listed by the European Union as Category 1 or 2 reproductive toxicant in EU Consolidated List Directive 76/769/EEC or listed as a reproductive/developmental toxicant under California Proposition 65.

Endocrine disruptors are any chemical listed by the European Union as a Category 1 or 2 endocrine disruptor in EU Consolidated List Directive 76/769/EEC. To be a Category 1 endocrine disruptor the chemical must have at least one study providing evidence of endocrine disruption in an intact organism. Category 2 endocrine disruptors have the potential for endocrine disruption.

Very persistent or very bioaccumulative chemicals are those listed by the Swedish National Chemicals Inspectorate's (KemI)[22]. The European Union defines "very persistent chemicals" as chemicals that have a half-life of greater than 60 days in water, or greater than 180 days in marine or freshwater sediment, or greater than 180 days in soil.[23] The European Union defines "very bioaccumulative" chemicals to have a bioconcentration factor for aquatic organisms of greater than 5000.[24] The European persistence lists do not include metals that are by nature infinitely persistent.

Inventorying Inputs and Outputs in the Life Cycles of the Plastics

Inputs: Primary raw materials: All the materials assessed here share a common primary raw material resource base: they are manufactured, at least in large part, from fossil fuels. The primary chemicals used to produce ABS, HDPE, PEX, and PP are derived from natural gas and crude oil.[25] The primary chemicals used to manufacture PVC are derived from a combination of these same fossil fuels and chlorine gas manufactured from brine (salt water). Chlorine makes up 57% of PVC in its raw pellet state. Each of these plastics also generally contains a range of additives discussed in further detail below.

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[17] The list of IARC evaluations can be found at: http://www-cie.iarc.fr/monoeval/grlist.html

[18] The US National Toxicological Program's Report on Carcinogens can be found at: http://ntp-server.niehs.nih.gov

[19] The consolidated version of Annex I of Directive 76/769/EEC (currently in force) including a consolidated list of CMR substances can be found at: http://europa.eu.int/comm/enterprise/chemicals/legislation/markrestr/index.htm

[20] The list of chemicals as known to the State of California to cause cancer or reproductive toxicity by the California Office of Environmental Health Hazard Assessment (OEHHA) is listed at: http://www.oehha.ca.gov/prop65/prop65_list/Newlist.html

[21] There is no equivalent US list for mutagenicity, however mutagens may be searched at GENETOX & Chemical Carcinogenesis Research Information System, http://sis.nlm.nih.gov

[22] Swedish National Chemicals Inspectorate (KemI) webpage: http://prio.kemi.se.

[23] Swedish National Chemicals Inspectorate (KemI) webpage: http://prio.kemi.se. The International Joint Commission (IJC www.ijc.org) adopted an even more conservative definition of a "persistent toxic substance:" any toxic substance that bioaccumulates in the tissue of living organisms, or any toxic chemical that has a half-life greater than eight weeks (56 days) in any medium (water, air, sediment, soil, or living thing).

[24] Swedish National Chemicals Inspectorate (KemI) webpage: http://prio.kemi.se.

[25] Coal-based byproducts such as coke gases (gases produced when converting coal into coke) are another potential raw material source of feedstocks for plastics. However, in the U.S., natural gas and crude oil are the overwhelming source of raw materials for plastics' feedstocks, therefore coal processes are not included in this analysis.

Since ABS, HDPE, PEX, and PP share a common petrochemical resource base, material selection between them will have no effect on avoidance of chemicals from raw materials extraction and primary chemical production. PVC shares the same petrochemical resource base as ABS, HDPE, PEX, and PP. The difference with PVC arises due to its chlorine content - 57% of the weight of raw PVC (before additives) is from chlorine manufactured from brine (salt water) instead of from petrochemicals. Appendix 3 lists the Priority Chemical outputs from chlorine production, fossil fuel extraction and refining for comparison[26]. Chlorine production has POPs outputs that aren't associated with fossil fuels (PCBs and hexachlorobenzene) while fossil fuels have POPs outputs not associated with chlorine production (aldrin and DDT). Both also have outputs in the other categories of Priority Chemicals of High Concern (US EPA PBTs and OSPAR and EPA Priority Chemicals). Therefore, neither crude oil refining or chlorine production is environmentally superior; both have significant priority chemical hazards associated with their output byproducts. It should be noted that chlorine production has a very serious mercury problem associated with it[27] and that chlorine itself is a highly toxic material.

This comparative analysis therefore focuses on the life cycle concerns after the initial raw material processing stage; that is after the raw material extraction, crude oil refining, natural gas processing, and chlorine production.

The assessment begins with an inventory of the principal organic chemicals used in the manufacture of the five plastics. Table 2 lists those chemicals for each plastic.

Table 2. Principal Organic Feedstocks Used to Manufacture Primary Pipe Polymers				
PVC	ABS	PEX	PP	HDPE
Ethylene	Ethylene	Ethylene	Propylene	Ethylene
Ethylene dichloride	Benzene			
Vinyl chloride monomer	Ethylbenzene			
	Styrene			
	Acrylonitrile			
	1,3-Butadiene			

Inputs: Additives: All petrochemical plastics require additives to either facilitate the manufacturing process or to impart specific properties to the final product. The types of additives commonly used in plastic pipes include: antioxidants, antistatic agents, lubricants, ultraviolet (UV) stabilizers, and heat stabilizers. The specific additives used in plastic products, including pipes, are proprietary data and can vary widely among manufacturers; hence complete information was not available for this analysis.[28] Generic formulations that listed specific chemicals were found only for PVC sewer pipes used in Europe (see Appendix 4).

While specific chemical formulations for the additives used in each plastic pipe polymer were not available for this analysis, substantial generic data on additive practices were collected and assessed. This report:

- Identifies the types of additives used in the manufacture of the plastic pipes: for example, UV light stabilizer.[29]

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[26] There are no known Priority Chemical outputs from brine production but there is insufficient data available for conclusion in this analysis.

[27] Nine chlor-alkali plants producing chlorine for PVC manufacture use mercury cell technology. Serious discrepancies and purchases indicate that the plants were not able to account for 65 tons of mercury in 200, more than emitted by all coal fired power plants. U.S. Senate Committee on Environment and Public Works "Senators Call On EPA To Document The Fate Of 65 Tons Of Toxic Mercury" http://epw.senate.gov/pressitem.cfm?party=dem&id=221813

[28] For example, in the case of ABS polymers, "Different manufacturers produce and process ABS significantly differently. Therefore, the selection of stabilizers has to be checked carefully for each process and application." Zweifel, 2000 p.78

[29] Sources include: *Chemical Economics Handbook*, "Plastics Additives" section by Modler, et. al. (1997); and the *Plastics Additives Handbook*, edited by Hans Zweifel (2000).

- Identifies the classes of chemicals used within each additive category: for example, benzophenone light stabilizers for the additive UV light stabilizer.[30]

- Identifies specific chemicals used as additives for specific polymers. For example, the UV light stabilizer 4-dodecyloxy-2-hydroxybenzophenone has been used as an additive in the manufacture of all five plastics considered in this report (ABS, HDPE, PEX, PP, and rigid PVC).[31] However, no data were located specifying the types of products using 4-dodecyloxy-2-hydroxybenzophenone.

The types of additives used to manufacture pipe grade polymers include:

- Lubricants and UV light stabilizers in all five plastics.
- Antioxidants and antistatic agents in ABS, HDPE, PEX, and PP.
- Stabilizers in PVC.

Carbon black is a common UV light stabilizer used in the manufacture of plastic pipes.

See Appendix 5 for a complete listing of classes and where they are used.

Note that the analysis is limited in scope on the specific additives used to manufacture each type of plastic pipe as this data is considered proprietary by manufacturers. To fully assess the relative toxicity of the polymers the City of San Francisco could collect data on the specific additives used in the manufacture of pipes. Due to the proprietary nature of this information, it is likely that the City of San Francisco would need to sign non-disclosure agreements or use an independent third party vehicle to gather and evaluate the data without making it subject to public disclosure.

Outputs: The toxic outputs - the releases of pollutants to air and water - are then inventoried for each stage of production of the principal feedstocks as well as for polymerization and compounding of the plastics. To inventory the full scope of pollutants generated and released during production, even those chemicals released in small quantities,[32] this inventory uses the raw data tables in the life cycle assessment study completed by Tellus Institute.[33] The data tables in the Tellus study are quite useful in identifying pollutants that are present in the wastewater and air emissions from manufacturing processes, but that do not appear in the US EPA's Toxic Release Inventory (TRI) due to falling under the TRI's emissions reporting threshold of 10,000 pounds.

Note that in this assessment all inputs into manufacturing– both principal feedstocks and known additives (or additive classes where the exact additives are not known) -- are included. For outputs, however, only the pollutants from principal feedstocks are identified and assessed. The pollutant outputs from the production of additives have not been identified nor assessed.

Transportation: Inputs and outputs to transportation of pipes and their feedstocks are not included in the scope of this assessment. It is assumed that selection of plastic type will not consistently or inherently affect the type of transportation modes or fuel types. Therefore the chemical hazard of transportation inputs and outputs will not be affected by plastic type selection.

Installation: Chemicals associated with the pipe installation process are also not formally included in this assessment. It should be noted, however, that PVC and ABS use solvent based systems with known chronic toxicants[34] whereas the polyolefins exclusively utilize mechanical or thermal joining methods with no direct chemical inputs. This is not expected to change the rankings as it parallels the hazards identified elsewhere in the life cycle.

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[30] Ibid.
[31] Radian Corporation, 1987. Radian Corporation. 1987. *Chemical Additives for the Plastics Industry: Properties, Applications, Toxicologies.* Park Ridge, NJ: Noyes Data Corporation.
[32] For example, below Toxics Release Inventory reporting thresholds.
[33] Tellus, 1992. While the data in the Tellus Institute report is from the 1980s, it represents the most comprehensive, publicly available database that includes the soup of pollutants released from these processes at very low levels.
[34] Common elements of PVC pipe cement include tetrahydrofuran (suspected endocrine and developmental toxicant with inadequate carcinogenicity data to classify), methyl ethyl ketone (another (suspected endocrine and developmental toxicant), and cyclohexanone (another (also a suspected developmental toxicant) and PVC resin. ABS cement typically consists of methyl ethyl ketone and ABS resin

Hazards Assessment of the Chemicals

Priority Chemicals of Highest Concern: The assessment compares the inventory of chemical inputs and outputs against the Chemicals of Highest Concern (Stockholm POPs, EPA PBTs, and EPA/OSPAR Priority Chemicals). For the five plastic polymer life cycles, these chemicals are primarily found as pollutant outputs: the pollution from manufacture, use and disposal.

Appendix 3 details where in the life cycle of the five plastics these Chemicals of Highest Concern to governments are created as pollutant outputs.

The results of this analysis are as follows:

* **Inputs:** Only PVC uses Chemicals of Highest Concern in manufacturing– the additives organotins, lead, and cadmium, which are OSPAR Chemicals for Priority Action.

* **Outputs (byproducts):** All of the plastics have both US EPA Priority PBT pollutants and OSPAR Chemicals for Priority Action associated with their life cycle: in the wastewater effluent from the manufacture of petrochemical feedstocks.

  PVC pipes are alone, however, in having Stockholm Convention POPs (dioxins, furans, PCBs, and hexachlorobenzene), as outputs in their life cycle beyond the initial raw material processing stage.

Chronic Toxicants, Persistent Chemicals, or Bioaccumulative Chemicals: The assessment then compares the inventory of chemical inputs to specific chemical hazards -- persistence, bioaccumulative capacity, and chronic toxicity -- for the primary organic chemical feedstocks and additives.

Appendix 6 details the toxicity of known inputs into each of the plastics.

The results include:
* All of the plastic pipes use a carcinogen (carbon black) for applications where the pipe may be exposed to UV light.

* Otherwise, ABS and PVC alone use:
  o carcinogens,
  o mutagens,
  o reproductive/ developmental toxicants, and
  o endocrine disruptors
  as either inputs into the manufacturing process and/or as inputs into the final product, even for non-UV protected product.

Note that unlike with PVC, where there are classes of chemicals used as stabilizers that are clearly hazardous (e.g., cadmium compounds, lead compounds and organotins), there are no such clearly hazardous classes of chemical additives used in ABS, HDPE, PEX, and PP pipes. For example, ABS, HDPE, PEX, and PP all use phenolic-based antioxidants. Unlike the lead compounds used in PVC pipes, hazards have not been identified for phenolic-based chemicals as a class. There is a phenolic-based antioxidant that is known to be an endocrine disruptor, bisphenol A. However, the only evidence found on the use of bisphenol A as an antioxidant states that it is used in PVC production[35].

This study evaluates the plastic manufacturing process inputs against the listings for both
A) the identified Chemicals of Highest Concern and
B) persistence, bioaccumulative capacity, and chronic toxicity.

The outputs, however, are only compared for Chemicals of Highest Concern. Since all of the plastics examined in this report have pollutant outputs that include a large number of additional chemicals that are persistent, bioaccumulative, or toxic, further evaluation from a chemical hazard screening perspective did not reveal any significant differences among the plastics.

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[35] Noyes, 1987 note there is also some evidence that bisphenol A may also be used as a flame retardant in ABS, although it is unknown if this occurs in pipes.

Summary and Findings of the Hazards Assessment

Table 3 summarizes the data collected concerning the life cycle hazards to human and environmental health associated with the five plastics commonly used in pipes: ABS, HDPE, PEX, PP, and PVC.

None of the plastics can be characterized as completely environmentally sound from this hazards assessment:

- **Inputs**: All of the plastics -- **ABS, HDPE, PEX, PP, and PVC** -- use the **carcinogen carbon black** for pipes that may be exposed to UV light

- **Outputs**: All the plastic piping materials examined here -- **ABS, HDPE, PEX, PP, and PVC** -- have both **US EPA Priority PBTs and OSPAR Chemicals for Priority Action** pollutant outputs associated with their life cycle: these occur in the wastewater effluent from the manufacture the petrochemical feedstocks used to make the plastics. All of the plastics also have a significant number of other listed persistent bioaccumulative or toxic outputs.

ABS and PVC, however, stand out for their hazards due to their unique association with key chemicals of concern in their life cycles:

- **Inputs: ABS and PVC** alone use **carcinogens**[36]**, mutagens, reproductive/developmental toxicants, and endocrine disruptors** either as inputs into the manufacturing process and/or as inputs into the final product, even for non UV protected product. **PVC** is the only plastic examined here to use **OSPAR Chemicals for Priority Action** in the final product itself.

- **Outputs: PVC pipes** are the only plastic pipe to have **Stockholm Convention POPs** (dioxins, furans, hexachlorobenzene and PCBs) associated with their life cycle after petroleum refining.[37]

ABS and PVC are considered environmentally less preferable in this analysis than HDPE, PEX, and PP because of their use of chronic toxicants as inputs in production that the other plastics avoid altogether. **PVC is judged less preferable than ABS** due to its unique association with outputs on the highest priority list (Stockholm POPs) throughout its life cycle (in the manufacture of its feedstocks and associated with the incineration of PVC products and accidental building fires) and for its use of US EPA and OSPAR Priority Chemicals as inputs. There is no differentiation between the other three plastics in this analysis. Table 3 summarizes the hazard assessment.

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[36] As noted above the other plastics do use one carcinogen – carbon black – for UV protected pipe.

[37] Note that this analysis did not include transportation impacts as described above.

Table 3. Plastic Pipe Hazard Assessment – Chemicals of Highest Concern

	Avoid	High Concern	Moderate Concern		
	PVC	ABS	PEX	PP	HDPE
Summary chemical hazard assessment	·EPA PBT & ·EPA/OSPAR Priority outputs plus ·Stockholm/OSPAR outputs & ·EPA/OSPAR Priority inputs & ·additional Chronic toxicant Inputs	·EPA PBT & ·EPA/OSPAR Priority outputs plus additional ·Chronic toxicant inputs	·Significant EPA PBT & EPA/OSPAR Priority outputs	·Significant EPA PBT & EPA/OSPAR Priority outputs	·Significant EPA PBT & EPA/OSPAR Priority outputs

Chemicals Of Highest Concern On Regulatory Target Lists – Process Inputs

	PVC	ABS	PEX	PP	HDPE
Stockholm POPs					
US EPA PBT					
US EPA Priority Chemical	Cadmium, Lead				
OSPAR	Cadmium, Lead Organotins,				

Chemicals Of Highest Concern On Regulatory Target Lists – Pollution Outputs (post initial raw material processing)

	PVC	ABS	PEX	PP	HDPE
Stockholm POPs	Dioxins, Furans, PCB Hexachlorobenzene,				
US EPA PBT	Dioxins, Furans, Benzo(a)pyrene, Hexachlorobenzene, Hg, PCB, OCS	Benzo(a)pyrene, Hg, Lead	Benzo(a)pyrene, Hg	Benzo(a)pyrene, Hg	Benzo(a)pyrene, Hg
US EPA Priority Chemical	Cd, Dioxins, Furans, Hexachlorobenzene, PAHs, PCB, PCP	Cd, PAHs	Cd, PAHs	Cd, PAHs	Cd, PAHs
OSPAR	Cd, Dioxins, DEHP, Furans, PCB,PCP,PAHs	Cd, DEHP, PAHs	Cd, DEHP, PAHs	Cd, DEHP, PAHs	Cd, DEHP, PAHs

Chronic Toxicants, Very Persistent, or Very Bioaccumulative – Process Inputs

	PVC	ABS	PEX	PP	HDPE
Carcinogens	Cd, Carbon black, EDC, Lead compounds, VCM	1,3-Butadiene, Acrylonitrile, Benzene, Carbon black, Ethylbenzene, Styrene	Carbon black	Carbon black	Carbon black
Mutagens	Cadmium	1,3-Butadiene			
Reproductive / developmental toxicants	Cadmium, Lead compounds	1,3-Butadiene, Benzene			
Endocrine disruptors	Organotins	Styrene			
Very persistent chemicals					
Very bio-accumulative chemicals					

Recyclability Assessment

The ideal end of life options for a product allow it to be: a) reused as the same product (e.g., reusable glass or plastic bottles), b) recycled back into the same product, "closed loop recycling" (e.g., aluminum cans), or c) biodegraded into healthy nutrients for the soil (e.g., organic food). Less preferable than these options -- although more preferable than landfilling or incineration -- is the recycling of a product into a lower value product (e.g., office paper into cardboard boxes): this is called "downcycling." The dominant end of life option for plastic pipes, however, is disposal in either a landfill or incinerator.

This evaluation of the end of life potential for the different plastic pipes is based upon two characteristics:
- current recycling rates and practices, including downcycling, and
- potential recyclability, including integration into a cross industry commodity plan

SF recycling: The current reality of plastic pipe recycling is that the recycling of these products is marginal: very few plastic pipes are recycled in the U.S and most of them are downcycled. In San Francisco, as with most municipalities, plastic pipe is not accepted in residential curbside recycling programs or at drop off centers. Additionally, a survey of firms that recycle construction waste in the Bay Area revealed that most do not accept plastics of any type. Of the firms that do accept plastic building materials, the vast majority only accept HDPE or PP. A smaller number accept ABS, very few accept PVC and none are known to accept PEX[38]. See Table 5 for count of firms in the Bay area that accept the different plastics.

Most efforts to recycle plastic building materials have been thwarted by the daunting problem of creating a secondary material with market value. Establishing an infrastructure to gather, sort, and create a homogenous secondary plastic stream from building materials typically results in a material that costs more than virgin plastic and meets lower performance specifications.

Cross industry efforts: Office furniture maker Herman Miller is exploring solutions to the problem of material recycling in general and plastics recycling in particular by engaging other industry sectors in closing the recycling loop. One concept under exploration is to establish consistent plastic specifications and product labeling, in order to establish a broader commodity market for recycled plastics that could be utilized by manufacturers in different industry sectors. This requires a reversal away from the trend of the last several decades to more designer plastics that are custom tailored to each narrow application. Instead it favors standardization of plastic formulas for use in the widest range of applications[39].

To further understand the potential recyclability of the different pipe plastics and how they are positioned for this type of cross industry commodity recycling effort, the current practices in two other sectors where significant recycling is underway - bottles and automotive part - are assessed.

Bottle recycling: Bottle recycling drives the recycling rates of plastics in the U.S. A recent assessment of the state of plastics bottle recycling by the state of California found that:[40]
- plastics recycling rates continue to lag behind other materials like steel, aluminum, glass, and paper (p.1)
- plastics recycling is largely uneconomical without subsidies (p.1)
- the most recycled plastics nation-wide are PET and HDPE, which account for "more than one-half of national plastics recycling" (p.8)
- other plastics "recycled in significant quantities are polypropylene battery casings; HDPE, LDPE, LLDPE stretch-wrap and film; PET X-ray films; and polystyrene protective packaging" (p.8)

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[38] This analysis is based upon listings as of January 2005 in the Plastics Directory compiled by the San Francisco Department of the Environment. http://temp.sfgov.org/sfenvironment/directories.plastic/htm
[39] Public presentation by Gabe Wing Miller of Herman Miller, Working Towards a Better World, US Green Building Council, Northern California Chapter, San Francisco, CA, January 18, 2005.
[40] California Integrated Waste Management Board, Plastics White Paper: Optimizing Plastics Use, Recycling and Disposal in California (2003) http://www.ciwmb.ca.gov/Publications/default.asp?pubid=1010

- PVC is a contaminant in plastics recycling: "Contaminants such as other resin grades (especially PVC)" and other materials "require extensive sorting and cleaning" (p.15)
- the recycling rate in California in 2001 for PET bottles was 36%, for HDPE bottles it was 38%, for PP bottles it was 7%, and for PVC bottles it was 1% (pp.32-33)

From the California Integrated Waste Management Board's report emerge the following conclusions. First, the municipal recycling infrastructure in the U.S. is primarily oriented to the recycling of HDPE and PET. Second, the secondary plastics recycled in the U.S. are overwhelmingly from the polyolefin plastics of polyethylenes (HDPE, LLDPE, and LDPE) and polypropylene. Third, PVC is a contaminant, not a valued commodity, in the municipal recycling stream. From these conclusions a crude plastics' recycling hierarchy emerges in the U.S., with PET and HDPE the most recyclable plastics, followed by other polyolefins, and with PVC the most undesirable (see Table 5).

Automotive recycling: The state of plastics recycling in the U.S. mirrors current developments in the automotive sector in Europe and Japan. With legislation requiring the take back of vehicles in Japan and the European Union, automakers are evaluating and selecting for plastics that are more recyclable. Pressed to recycle ever greater percentages of end-of-life vehicles, automakers have completed some of the most extensive assessments on the recyclability of plastic materials.

For example, in 2001, Opel (a European division of General Motors) published its plastics recyclability hierarchy in its environmental report (see Table 4 below). The preferred plastics for recycling were the polyolefins (PP and PE) and the least preferred plastics were a "mixture of incompatible materials" and "PVC."

Table 4. Opel Priority List for Plastics with Regard to Recycling Aspects[41]	
Increasing preference→Prefer / Avoid→	Polypropylene (PP), Polyethylene (PE)
	Polyoxymethylene (POM), Polyamide, Thermoplastic Urethane (TPU)
	Acrylonitrile Butadiene Styrene (ABS), Polymethylmethacrylate (PMMA, i.e., acrylic), Styrene Maleic Anhydride (SMA) copolymer, Acrylonitrile Styrene Acrylate (ASA), Styrene Acrylonitrile (SAN)
	Polycarbonate, Polyethylene Terephthalate (PET), Polybutylene Terephthalate (PBT)
	Thermoplastic Elastomer (TPE)
	Polyurethane
	Sheet Molding Compound (SMC), Phenol-Formaldehyde (PF)
	Elastomer
	Polyvinyl Chloride (PVC)
	Mixture of incompatible materials

Opel is not alone in its assessment of plastics. Honda, Nissan, and Toyota have all identified polyolefins as the preferred plastics from the perspective of recyclability. Honda, for example, states in its 2003 Environmental Annual Report that it is standardizing for polyolefin resins: "For all of the new models and changed models released in fiscal 2002, highly recyclable olefin resins are now used for injection-molded interior parts"; including trunk decoration, instrument panels, bumper faces, air conditioning units, and door linings.[42] Polypropylene bumpers are now widely recycled in Japan. Nissan, for example, collected 231,576 polypropylene bumpers in 2002 for use as used bumpers (as replacement parts) and with the goal of using the recycled bumpers on new models.[43] Regarding PVC, Toyota in its 2003 Environmental and Social Report stated that it "is actively engaged in reducing the volume of PVC resin used."[44]

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[41] Opel. 2001. *Environmental Report 2000/2001.*
[42] Honda. 2003. *Environmental Annual Report 2003*, p.32.
[43] Nissan, 2003. *Environmental and Social Report (year ended March 31, 2003*, pp.32+38.
[44] Toyota. 2003. *Environmental & Social Report 2003*, p.37.

PEX is not referenced in these reports due to its low usage in these sectors. PEX recycling is hampered by the crosslinking of the molecules. Cross-linked plastics like PEX are known as "thermoset" plastics. A thermoset plastic is hardened by curing, creating a three-dimensional, inter-connected structure that cannot be re-melted or re-molded; it is infusible and insoluble.[45] This makes thermosets like PEX very difficult to recycle. The only current recycling option for PEX is to grind it down and use as filler in another material.

Table 5 summarizes the data collected on the recycling and recyclability of the plastics used in pipes. The polyolefins -- especially HDPE (municipal bottle recycling) and PP (automotive sector) -- are the preferred pipe plastics used in for municipal and automotive recycling programs and with the most acceptance by regional plastic recyclers in the Bay area. ABS is recyclable but receives little attention in these assessments of plastics recycling because of its smaller levels of production relative to HDPE, PP, and PVC. PEX receives little attention because it is both a relatively small volume plastic and inherently very difficult to recycle.

PVC is a plastic that municipal and automotive recycling programs are actively avoiding. The array of toxic additives included in PVC (as discussed in the previous life cycle section) as well as it being a contaminant in municipal recycling, make it a largely unwanted post-consumer material. While manufacturers of PVC -- especially in Europe -- are trying to develop a post-consumer recycling market for PVC, their initiative is receiving a lukewarm response from the users of plastics, as exemplified by the automotive sector's decision to de-select PVC.

Table 5. Assessment of Recyclability of Plastics Used in Pipes					
	Avoid		Concern	Prefer	
	PVC	PEX	ABS	PP	HDPE
Summary assessment	·Little recycling. ·Considered a contaminant to municipal recycling	·Very limited. ·Only recycled as filler in other products. Can never be closed loop recycled.	·Recyclable but small markets	·Established post consumer recycling markets (automotive)	·Established post consumer recycling markets (bottles)
SF area recycling outlets	5 companies accept drop off	None known in bay area	7 companies accept drop off, many w/min-imum amts	11 companies accept drop off	13 companies accept drop off
Municipal bottle recycling	Contaminant in bottle recycling streams	Not applicable, no use in this sector	Not applicable - recyclable but little use in this market	Marginal levels of recycling	Highly recyclable, well established markets
Automotive recycling	Among the least preferred plastics	No data on PEX use and recycling in this sector	Recyclable, moderately preferred, but used in low volumes	Highly recyclable, established markets, most preferred	Highly recyclable, established markets, most preferred

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[45] Stevens, 2002, p.39. HDPE, PP, ABS, and PVC are all "thermoplastics." Since thermoplastics can be repeatedly softened and hardened by heating and cooling, they are much easier to recycle than thermosets.

Summary of Environmental Preferability Analysis

The hazards and recyclability assessments clearly indicate that PVC is environmentally less preferable than HDPE and PP. ABS and PEX occupy a middle ground between the poles of PVC -- to be avoided -- and HDPE and PP -- to be preferred (see Table 6). ABS is in the middle ground because of its better recycling profile than PVC. For PEX, while it is preferable to ABS and PVC on hazards, questions remain about its recyclability.

- ABS and PVC have more significant Chemicals of Highest Concern across their life cycles than HDPE, PP, and PEX,

    o PVC is of somewhat greater concern than ABS because of its linkage with chemicals targeted for elimination by international treaty: the Stockholm Convention on POPs

- PVC has a negative recycling profile: it is considered a contaminant in municipal recycling programs.

- ABS and PEX have limited to no recyclability data.

- HDPE through packaging and PP through the automotive sector both have established post-consumer recycling markets.

There are no rating differences between HDPE, PEX and PP in the hazards assessment portion of this analysis. PEX ranks below HDPE and PEX due to its lack of recyclability Therefore HDPE and PP share the highest relative environmental preferability ranking in this assessment, followed by PEX. It is important to keep in mind when reading this analysis that all of these plastics have significant toxicity problems and much of the recycling is still downcycling. There remains much work to be done to find truly environmentally healthy plastics for these applications.

Table 6. Combined Preferability of Pipes based on Hazard and Recycling Assessments				
	Avoid	Concern		Prefer	
	PVC	ABS	PEX	PP	HDPE
Summary chemical hazard assessment	·EPA PBT & ·EPA/OSPAR Priority outputs plus ·Stockholm/OSPAR outputs & ·EPA/OSPAR Priority Inputs & ·additional Chronic toxicant Inputs	·EPA PBT & ·EPA/OSPAR Priority outputs plus additional ·Chronic toxicant inputs	·Significant EPA PBT & EPA/OSPAR Priority outputs	·Significant EPA PBT & EPA/OSPAR Priority outputs	·Significant EPA PBT & EPA/OSPAR Priority outputs
Summary recycling markets and recyclability assessment	·Little recycling. Considered a contaminant to municipal recycling	·Recyclable but small markets	·Very limited. Only recycled as filler in other products. Can never be closed loop recycled.	·Established post consumer recycling markets (automotive)	·Established post consumer recycling markets (bottles)
Remember that all of these plastics have significant toxicity problems and much of the recycling is still downcycling. There remains much work to be done to find truly environmentally healthy plastics for these applications.					

Performance Evaluation

The final step of this analysis evaluates the performance characteristics for each pipe plastic in different applications. Performance of the different pipe plastics are evaluated for the following applications:
- Water Distribution
- Drain Waste and Vent (DWV)
- Sanitary Sewer
- Storm Sewer
- Irrigation and Drainage

The discussion of characteristics is qualitative where a specific rating measure is not listed. Performance characteristics will be compared across pipe plastics and for their impact on the usefulness of the pipe plastic for each of the applicable applications.

Polyvinyl Chloride (PVC) provides a good combination of long-term strength and high stiffness. PVC has good chemical resistance to a wide range of corrosive fluids, but may be damaged by ketones, aromatic and some chlorinated hydrocarbons. It is used in DWV, storm, sanitary, and water distribution applications.[46] PVC pipe is primarily joined by either by bell and spigot or by chemical solvent cementing - which has additional toxicity problems not addressed in this report.

Acrylonitrile-Butadiene-Styrene (ABS) is formed from three distinct monomer building blocks. Substances of these types are usually referred to as copolymers. The proportions of each substance will determine the physical properties of the final product. In this case, acrylonitrile contributes rigidity, strength, hardness, and chemical and heat resistance. Butadiene contributes impact resistance. Styrene increases the ease of processing. ABS is primarily used for DWV applications. ABS pipe can be joined by solvent welding or threading.[47]

High Density Polyethylene (HDPE) exhibits good chemical resistance, flexibility (without the addition of plasticizers) and abrasion resistance. It can be used for pressure and non-pressure applications and is increasingly available with higher pressure ratings. HDPE retains its strength and flexibility even at subfreezing temperatures. Its inherent flexibility provides better resistance to ground movement, earthquakes, and damage during installation or intrusion during excavations. The flexibility of HDPE has also made it increasingly popular in some parts of the country (including the San Francisco area) for trenchless sewer replacement, providing significant savings in trenching costs and environmental impact. Coiling is possible with small diameter polyethylene pipe which makes it useful for gas distribution and water services. In some applications flexible HDPE pipe can provide cost savings by minimizing and eliminating the need for jointing. The pipe can be bent around corners and around physical obstructions.

The principle joining method is heat fusion, where pipe ends are thermally butt-fused together. This can make a virtually leak-proof joint stronger than the pipe itself and considered by some to be superior to the solvent welds or threaded joints of PVC and ABS. HDPE may also be joined by other methods such as compression fittings.

The primary HDPE applications are: irrigation and drainage, water and storm and sanitary applications[48].

Cross Linked Polyethylene (PEX) is made up of polyethylene molecules that are cross linked in order to raise the maximum operating temperature up to 200 °F (93 °C). Other performance characteristics are similar to HDPE. Common applications are primarily inside buildings, including under-floor hydronic heating systems, and hot-cold water systems. PEX pipe is primarily available in small sizes appropriate to these applications. Connections are primarily made with compression fittings.

Polypropylene (PP) shares similar properties with polyethylene and generally has better chemical resistance than other plastics. PP is used in some pressure piping applications, but its primary use is in low pressure lines. Polypropylene plastic pipe is used for chemical (usually acid) waste drainage systems, sanitary and water lines, though almost exclusively outside of North America. In 2004, however, a

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[46] CBD-220. Thermoplastic Pipe, National Research Council of Canada, Institute for Research in Construction http://irc.nrc-cnrc.gc.ca/cbd/cbd220e.html
[47] CBD-220
[48] CBD-220

German firm, Aquatherm, began marketing PP in North America for potable-water, hydronic-heating, and other pressurized piping applications[49]. Another manufacturer intends to introduce a PP sanitary line in 2005[50]. Pipe lengths are joined by heat fusion, threading (i.e., with heavy pipe) and mechanical seal devices.[51]

Pipe Sectors

Within each sector, design, construction and operational and maintenance considerations impact plastic selection. As these sectors differ from one another, it is important to recognize that one plastic may not be appropriate for use over all sectors.

Water Distribution

Water distribution systems are defined as those that convey potable water, typically from water treatment facilities, to the end user. These systems are a tree-like pipe network consisting of:
- Transmission lines - (water mains - typically 36" diameter or less)
- Distribution lines - (lower diameter sizes: 6" - 12")
- Service connections - (from street to building)

Water mains typically operate at pressures from 100 to 150 lbs per sq. in. (psi), while distribution lines operate between 40 and 100 psi[52].

The primary plastics used for water distribution in North America are HDPE and PVC. HDPE pipe performs roughly equivalently to PVC in water main applications, with similar corrosion resistance and durability. HDPE has a slight advantage in terms of preventing leaks as the butt-fusion method used to join HDPE provides stronger, tighter, more leak proof joints compared to the bell and spigot joints used in PVC pipe[53]. PEX is also used in this application, primarily for small diameter distribution applications within buildings. PEX is generally not used for the other applications surveyed here.

Drain, Waste and Vent (DWV)

DWV is essentially the sanitary sewer system before it leaves the property line. PP, PVC, HDPE and ABS are all in use in DWV applications domestically and/or in foreign markets. Because of the wide range of labor, fire and other code issues, selection of DWV can be challenging in North America and one or more of these alternatives has been restricted for DWV use in the USA. For example, New York State labor code prohibits the use of PVC pipe in buildings greater than three stories. Fire codes may prohibit the interior use of HDPE in some states. A full analysis of code restrictions on pipe alternatives in DWV is beyond the scope of this report.

Sanitary Sewer

Sanitary sewers collect wastewater from homes and business and convey it for treatment. Sanitary sewer collection systems, like water distribution systems, are a tree-like pipe network and consist of:
- Interceptor Sewers – (carry wastewater from collecting sewers to the wastewater treatment facility. From 15" up to several feet in diameter)
- Collecting Sewers – (collect from service connections with typical diameters of 6" to 12")
- Service connections – (from street to building).

Sanitary sewers release corrosive gases. Because of the resistance to corrosion provided by the plastics, they are increasingly preferred to non-plastic alternatives for sanitary applications. Currently, PVC is the most widely used plastic for sanitary sewer in North America but HDPE is gaining market share in some areas, including the San Francisco area, particularly for its ability to be used for trenchless sewer replacement (not possible with PVC). HDPE also has a slight advantage in chemical and abrasion

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[49] Environmental Building News, "Fusiotherm Polypropylene Piping From Aquatherm", September 2004 Volume 13, Number 9
[50] Personal communication with Jamie Harvie.
[51] CBD-220 NRC
[52] Environment Canada, "A Technical and Socio-Economic Comparison of Options to Products Derived From the Chlor-alkali Industry" 1999
[53] Environment Canada

resistance. On the other hand, gravity lines, such as sewer and drainage require close attention to proper installation gradient to ensure proper flow, whereas pressure lines which do not require this gradient, offer greater leeway. As a result, gravity line pipe is typically installed in sections which allow closer installation and monitoring, which is more difficult with the use of long, more flexible, continuously welded pipe. This has made HDPE more popular for trenchless replacement slip lining than for new sanitary gravity pipe lays, but not exclusively. Hancor, a US pipe manufacturer has just introduced a HDPE pipe, which comes in 20 foot sections and intended for sanitary applications. Available in larger diameters, the pipe is joined through fusion welding.

In Europe, more rigid PP is gaining in popularity. Though it has not yet been marketed for this application in the US, a European manufacturer plans to market a PP pipe for sanitary applications in the US market[54].

Storm Sewer

Prior to the 1960s most sewer systems were combined sewers, that is, carried both sanitary and storm water. The system had to be designed to carry large volumes of water during rain events, but otherwise the capacity was little used. In addition, when it did rain the flood of relatively fresh water often negatively impacted water treatment. Design changed so that by the mid 1960s sanitary and storm systems were designed and constructed separately. Storm sewers collect water from roof drains, parking lots and streets. Unlike sanitary sewers, storm wastewater is not typically treated and the flow is directly discharged into a receiving body of water. PVC and HDPE are the plastics most widely used in North America. Since storm sewers are also a non pressurized, gravity flow application, the performance concerns are similar to sanitary sewer applications, with the notable exception that corrosive gas resistance is less important.

Irrigation and Drainage

PVC, PP and HDPE are all used for irrigation water distribution in the US with similar performance characteristics. Because the distributed water is under pressure, leakage performance is again significant. PVC has dominated irrigation applications in recent years, but HDPE is now beginning to regain share due in part to the labor savings of layout from long coils with fewer joints versus the short rigid sections of PVC and its higher resistance to shovel damage and joint failure.

Plastic pipes, both PVC and HDPE, are gaining rapidly in the huge drainage market previously dominated by concrete and steel. Recently, the Corrugated Polyethylene Pipe Association initiated a third party certification system which allows for increased acceptance of their product by the American Association of State Highway and Transportation Officials. High recycled content HDPE is now available on the market for this application. Performance issues are similar to storm sewer applications.

Duct and Conduit

PVC and HDPE are both used for electrical duct and conduit. Rigid PVC can have an advantage in requiring fewer hangars in suspended applications. Flexible HDPE can have the advantage in easier installation for long continuous runs and bends without requiring joints. HDPE also has a lower coefficient of friction thus making cable fishing and pulling easier. Fire resistant HDPE is available. PP is also used where higher temperature resistance is required, but not widely available in North America.

Cost Issues

All pipe sectors have at least one viable plastic alternative, with the exception in North America of DWV, where there is still limited access to polyolefin based plastic pipes, although Aquatherm's market introduction may change this soon. The issue of cost differential is extremely complex. Conversation with industry officials and literature review suggest that pipe material cost differences, if they do exist, are not the determinant issue in pipe selection[55]. Pipe project costs are highly dependent on a number of important variables which include but are not limited to: market location and its proximity to

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[54] Personal communication with Jamie Harvie.
[55] For more discussion on this topic see Harvie, Jamie etal, "PVC-Free Pipe Purchasers' Report", Healthy Building Network 2002, http://www.healthybuilding.net/pvc/pipes_report.html

manufacturing, material/resin costs which can vary rapidly over time, soil and other site conditions, local labor costs, contractor experience with the pipe type, and installation method. While it is difficult to make across the board statements about the cost implications of plastic selection, a recent report found that less toxic alternatives are successfully competing with PVC in many pipe applications.[56]

Lifespan and Durability

There is much debate over the durability and expected lifespan of plastic pipes. The long term durability of piping systems depends on many factors, including the soil environment, proper installation, material properties such as corrosion resistance, chemical resistance and strength and the performance of joints[57]. Because of the characteristics of storm and sanitary flow, conveyance systems must offer good resistance to corrosion, chemicals and abrasion. All plastics under consideration offer good resistance to these forms of degradation. All of the plastics have been on the market for decades[58]. When properly designed and installed, pipe systems of any of these materials can be sufficiently durable to withstand many decades of services[59].

Summary of Performance Evaluation

Table 7 compares the relative performance and availability of the various plastics by application. ABS and PEX have characteristics that lead them to be used primarily in a limited number of applications. PVC, HDPE and PP meanwhile are competitive in most applications with many similar performance characteristics and modest tradeoffs in others. The net result is that plastic alternatives exist in the Prefer category (HDPE and PP) for each of the pipe applications studied that perform equal to or better than the plastics in the Concern or Avoid categories.

Market availability

While regional availability may vary, only the market availability of alternatives for DWV is significantly limited across North America, due in part to state and local building code challenges and part due to manufacturer market decisions. Differences in market share across the applications are primarily a function of the historical marketing focus of the manufacturers rather than of purchaser selection. For example, PVC manufacturers pursued municipal markets before HDPE; hence they have the dominant market share in municipal markets. Meanwhile, HDPE manufacturers targeted industrial markets where HDPE's corrosion resistance created performance advantages.

Access to alternative plastics is growing as manufacturers are increasingly targeting new markets across these traditional boundaries. European PP manufacturers are beginning to enter into the North American market and North American HDPE manufacturers are expanding their offerings to cover more applications. Even in the constrained North American DWV market, options are beginning to emerge. Forward looking environmentally preferable purchasing policies by corporate and government entities can aid this market transformation. There is no reason not to move forward in selection of more preferable alternative pipe plastics.

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[56] Ackerman, Frank, etal "The Economics of Phasing Out PVC", Tufts University, 2003
http://www.healthybuilding.net/pvc/Economics_Of_Phasing_Out_PVC.pdf
[57] Environment Canada
[58] PEX has only been in the North American market since 1995 but has been used widely in Europe for decades. Likewise PP has had relatively limited marketing in North America but has been widely used in Europe for decades.
[59] Environment Canada

Table 7. Application Specific Performance & Availability Comparison for Plastic Pipes					
	PVC	**ABS**	**PEX**	**PP**	**HDPE**
- Water distribution	Good/Good	Not used/NA	Good/ Good[x]	Good/Poor[†]	Good/Good[o]
- Drain/Waste/Vent	Good/Good	Good/Good	Not used/NA	Good/Poor[†]	Not used/NA
- Sanitary sewer	Good/Good	Not used/NA	Not used/NA	Good/Poor[†]	Good/Good
- Storm sewer	Good/Good	Not used/NA	Not used/NA	Good/None*	Good/Good
- Irrigation & drainage	Good/Good	Not used/NA	Not used/NA	Good/None*	Good/Good
- Duct & Conduit	Good/Good	Not used/NA	Not used/NA	Good/Poor*	Good/Good

First item before the "/" is the general performance assessment. The item after the "/" is the market availability assessment..

Not used means not typically specified or used in these applications. **NA** means market availability is not applicable as there is no demand because the plastic type is not typically used

[x] Used only in small diameter pipes, primarily for water distribution and radiant systems in buildings.

[o] Used primarily in large diameter piping outside the building

[†] Available in Europe, in early stages of marketing in US in 2005

* Available in Europe, not yet marketed in the US

See Appendix 7 for more detailed charts of plastic pipe performance by application

Conclusion

This study seeks to answer the question of whether there are significant differences between the plastics used to manufacture pipes with a focus on priority environmental health impacts and end of life recyclability. No determination is made on whether plastics are either more or less preferable to the traditional materials used to manufacture pipes. Rather the evaluation is for decision-makers interested in understanding the environmental differences between plastics.

In this report, the plastics used to manufacture pipes are analyzed and compared for chemical hazards, recyclability and performance. The chemical hazard and recyclability assessments evaluate the environmental sustainability of plastics, while the performance assessment gauges the technical, market, and economic viability of the materials in different applications.

Table 8 summarizes the results of the analysis and the conclusions of this report.

The analysis of the existing data leads to four primary conclusions:

- HDPE and PP are the most environmentally preferable plastics currently used to manufacture pipes under this chemical hazard and recyclability based analysis with no significant distinction between them. Yet even these plastics have their environmental downsides.
- HDPE, PP, and PEX create less chemical hazards of high concern across their life cycles than ABS and PVC.
- HDPE and PP are the most recyclable of the materials. There is less of a market for recycling ABS. PEX is not truly closed loop recyclable, and while PVC is marginally recyclable under some circumstances it is considered a contaminant in many recycling programs and increasingly avoided in some sectors.
- Plastic pipe alternatives exist in the Prefer category in this analysis (HDPE and PP) that perform equal to or better than the plastics in the Avoid and Concern categories (PVC, ABS and PEX) for each of the pipe applications studied. Availability of preferable alternatives is good in North American markets with the exception of drain-waste-vent (DWV) applications. The entry of new PP and HDPE products, with encouragement from environmentally preferable purchasing policies, is expected to expand availability of preferable alternative options in the North American market for all applications including DWV.

Table 8. Summary of Plastic Pipe Environmental Preferability Analysis

	Avoid	Concern		Prefer		
	PVC	ABS	PEX	PP	HDPE	Preferable
Summary of chemical hazard & recyclability assessments	·worst chemical hazard ·poor recyclability	·more chemical hazard ·low recycling	·less chemical hazard ·very limited recyclability	·less chemical hazard ·good recyclability	·less chemical hazard ·good recyclability	Truly preferable plastic pipes do not yet exist
--- Chemical Hazard Assessment ---------						
Stockholm POPs (outputs after refining)	Dioxins, Furans, Hexachlorobenzene, PCB	+ none	+ none	+ none	+ none	
OSPAR & USEPA PBT & Priority Chemical (inputs)	Cadmium, Lead, Organotins	+ none	+ none	+ none	+ none	
Chronic toxicants; Carcinogens, mutagens, developmental or reproductive toxicants or endocrine disruptor (inputs)	- Cadmium, Carbon black, EDC, Lead compounds, Organotins, VCM	-1,3-Butadiene, Acrylonitrile, Benzene, Carbon black, Ethylbenzene, Styrene	- Carbon black	- Carbon black	- Carbon black	
Other PBT Outputs	- many	- many	- many	- many	- many	
--- Recyclability Assessment----------						
Summary recycling markets and recyclability assessment	Little recycling. Considered a contaminant to municipal recycling	Recyclable but small markets	Very limited. Only recycled as filler in other products. Can never be closed loop recycled.	+ Established post consumer recycling markets (automotive)	+ Established post consumer recycling markets (bottles)	-
--- Performance / Availability Assessment----------						
- Water distribution	Good/Good	Not used/NA	Good/Good*	Good/Poor*	Good/Good*	
- Drain/Waste/Vent	Good/Good	Good/Good	Not used/NA	Good/Poor	Not used/NA	
- Sanitary sewer	Good/Good	Not used/NA	Not used/NA	Good/Poor	Good/Good	
- Storm sewer	Good/Good	Not used/NA	Not used/NA	Good/None	Good/Good	
- Irrigation & drainage	Good/Good	Not used/NA	Not used/NA	Good/None	Good/Good	

*PEX is used only in small diameter piping primarily for water distribution and radiant systems in buildings. HDPE for water distribution is used primarily in larger diameter piping outside the building. PP is just beginning to be marketed in North America

Appendix 1 - Principles of Decision Making: Life Cycle, Precaution & Pollution Prevention

The screening based method described in this report to evaluate the plastics used in pipes is founded upon three principles:

1) Life Cycle Thinking:

In life cycle thinking the stages of a material's life -- beginning with raw material extraction and ending with disposal (or reuse/recycling/composting) -- provide the frame for evaluating the presence of toxic inputs and toxic outputs. Life cycle thinking, as Todd and Curran (1999) emphasize, is "a unique way [relative to quantitative life cycle assessment (LCA)] of addressing environmental problems from a systems or holistic perspective" because it challenges the "need for a complete inventory of material and energy flows associated with the system of interest."[60] In fact, it challenges not only the need, but also the attainability and the practical usefulness of quantitative LCA in establishing materials policies such as this.

The method used here to evaluate plastic pipes does not attempt to quantify total outputs of toxic chemicals nor normalize results to a functional unit, but rather bases judgments upon screening simply for direct existence or nonexistence of target outputs.

Quantified risk analysis type approaches such as applied by most LCA tools are severely limited in their usefulness for policy judgments for a variety of reasons. Efforts to quantify impacts as they relate to human and ecological toxicity have run up against a number of significant barriers:

- Toxic chemical release data are a poor indicator of potential impacts because there is no simple linear relationship between measured releases and impacts.
    - Some chemicals persist in the environment, bioaccumulate in organisms, and biomagnify up the food chain. The result is that a given amount of release will result in widely different and not readily predictable exposures to different populations dependent upon factors like geography and location on the food chain.
    - Furthermore, many of these same chemicals are toxic at very low doses. Thus small releases of these chemicals – sometimes at levels well below thresholds that are easily monitored for quantification are of high concern. That is, any release – even a very small one - can result in significant exposures in humans and wildlife.
    - Adverse effects may be more a factor of the timing of the exposure -- e.g., the developing fetus exposed to phthalates -- rather than the dose of the exposure.
    - Individuals are exposed to a complex soup of chemicals - many that can cause the same adverse effects and some that are synergistic - rather than only to a single chemical at a time. Thus the cumulative doses of exposure to potential impacts are greater than assumed for any individual chemical. Additional exposures to a single chemical may have threshold or synergistic effects far beyond those predicted by one at a time controlled studies would indicate.

- LCA models suffer from a great paucity of comprehensive and reliably comparable data:
    - Release data is primarily based upon stack and pipe release estimates. Exposures that occur in the workplace, from the use of products, and from food are not included, although they are critically important additive factors to the impact.
    - Release data based upon the Toxics Release Inventory (TRI) database isn't even complete for stack and pipe releases as reporting requirements do not apply to all releasers.
    - Most LCA models are very limited in which datasets are incorporated and may be missing significant portions of life cycle releases.
    - Data are often of widely varying quality across materials and rarely transparent to the user for quality checking.

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[60] Todd, Joel Ann and Mary Ann Curran (eds.), 1999, *Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup* (Pensacola: SETAC).

- o The sheer volume of data inputs makes thorough quality checking impossible.
- o The large number of assumptions with high variability and uncertainty generally leads to a high uncertainty in the absolute metric that is rarely reflected in the results of LCAs despite the fact that these uncertainties can be much larger than the differences reflected in the LCA result.
- o Many simplifying assumptions and interpretive algorithms are needed to translate data into common metrics, compare different impact types and pathways and manage the different data sources. These each contain significant assumptions that are seldom transparent to the user.61

- The need to reduce everything to a common metric for LCAs requires reducing every human health impact -- including carcinogenicity, mutagenicity, and reproductive, developmental, and neurological toxicity to a relative quantitative value, masking core values.

LCAs have a place in narrowly defined industrial analysis for single manufacturers, where the data set is closely held and the set of parameters to capture is constrained, but for broader materials policy work like this it is sorely lacking. The task of quantification demanded by LCAs, is laborious, masks critical values and ultimately at this scale may be of questionable scientific validity.

The method used here based upon life cycle thinking instead uses a more straightforward knock-out screens for the most toxic chemicals of concern. That is, it sets screens for materials based simply upon use of these chemicals or the creation of them as byproducts instead of attempting to compare quantities and scale to assumed impacts.

2) Pollution Prevention:

Reducing toxicants before they are used or generated as byproduct has priority over controlling toxics at the end-of-the-pipe. The primacy of prevention is established in the Pollution Prevention Act of 1990:

> The Congress hereby declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

When developing a method where prevention has primacy over control, it places the emphasis of the analysis on evaluating whether a toxic chemical is present or absent in the life cycle of a material (just s the life cycle thinking approach does) -- as either an input or output in each stage of the material's life cycle -- rather than quantifying the amount of the chemical released into the environment for each stage. It is a binary system. Toxic chemicals are either present or not present. A binary system is particularly appropriate when dealing with PBTs, inasmuch as even low level releases can result in significant adverse public and environmental impacts. For example, the International Joint Commission (IJC) concluded in its *Sixth Biennial Report on Great Lakes Water Quality* that "we should immediately begin a process to eliminate" PBTs because "it seems impossible to eliminate discharges of these chemicals through other means." Therefore, continued the IJC, "a policy of banning or sunsetting their manufacture, distribution, storage, use and disposal appears to be the only alternative."[62]

The hierarchy of materials management established in the Pollution Prevention Act also emphasizes the importance of recycling materials before disposing of them. Therefore the method should include an assessment of whether materials are recycled, as well as the impacts that may occur from recycling.

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[61] See *Environmental Building News*, March 2002, "Life-Cycle Assessment for Buildings: Seeking the Holy Grail," Vol. 11, No. 3.
[62] International Joint Commission (IJC), 1992, *Sixth Biennial Report on Great Lakes Water Quality* (Washington, DC: IJC).

3) Precautionary Principle:

Precautionary approach to decision making is especially relevant to the proposed method:

San Francisco's Precautionary Principle Ordinance, passed in 2003, states that it is the responsibility of government agencies to take action to protect human health and the environment in the face of scientific uncertainty[63]. Traditionally governments ask, "How much environmental harm will be allowed?" in San Francisco, decision-makers ask a very different question: "How little harm is possible?"

Taking action on early warnings is incorporated into the screening method by selecting criteria that reflect the presence of materials known to be of concern due to their toxicity, persistence, and bioaccumulative properties. Historically, environmentally harmful activities have only been stopped after they have manifested extreme environmental degradation or exposed people to harm. In the case of PCBs, DDT, lead, and asbestos, for instance, regulatory action took place only after disaster had struck.

Seeking the safer alternatives is a central element of the precautionary approach and involves the careful assessment of available alternatives using the best available science[64]. An alternatives assessment examines a broad range of options in order to present the public with the consequences of each approach. The process takes short-term versus long-term effects or costs into consideration, and evaluates and compares the adverse or potentially adverse effects of each option, giving preference to those options with fewer potential hazards. The screening process used in this plastic pipe assessment presents decision makers with answers to these fundamental questions: "Is this potentially hazardous product necessary?" "What less hazardous options are available?" and "How little damage is possible?"

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[63] San Francisco Precautionary Principle Ordinance, Chapter 1 of Environment Code: www.sfenvironment.org
[64] Lowell Statement on Science and the Precautionary Principle (2001).

Appendix 2 - Chemicals Targeted for Elimination / Reduction by the Stockholm Convention, US EPA and OSPAR

CHEMICALS	Stockholm POPs[65]	US EPA PBTs[66]	OSPAR Priority Chemicals[67]	US EPA Priority Chemicals[68]
1,2,4,5-Tetrachlorobenzene				X
1,2,3-trichlorobenzene			X	
1,2,4-trichlorobenzene			X	X
1,3,5-trichlorobenzene			X	
2,4,5-Trichlorophenol				X
2,4,6-tri-tert-butylphenol (phenol)			X	
4-(dimethylbutylamino) diphenylamin (organic nitrogen compound)			X	
4-tert-butyltoluene (aromatic hydrocarbon)			X	
4-Bromophenyl phenyl ether				X
Acenaphthene				X
Acenaphthylene				X
Anthracene				X
Aldrin	**X**	**X**		
Benzo(a)pyrene		**X**		
Benzo(g,h,i)perylene				X
Brominated flame retardants (BFRs), incl. tetrabromobisphenol A (TBBPA)			X	
Cadmium and compounds			**X**	**X**
Chlordane	X	X		
clotrimazole (pharmaceutical)			X	
DDT	**X**	**X**		
dicofol (pesticide/biocide)			X	
Dieldrin	X	X		
Endosulfan (pesticide/biocide)			X	X
Endrin	X			
Fluorene				X
Heptachlor	X			X
Hexachlorobenzene	**X**	**X**		**X**
Hexachlorobutadiene				X
Hexachlorocyclohexane isomers (HCH) (pesticide/biocide)			X	X
Hexachloroethane				X
Hexachlorocyclopentadiene (HCCP)			X	
Hexamethyldisiloxane (HMDS) (organosilicane)			X	
Lead and organic lead compounds		**X**	**X**	**X**

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[65] The text of the Stockholm Convention can be found at: http://www.pops.int/documents/convtext/convtext_en.pdf
[66] The list of priority PBT chemicals for which the USEPA is developing national action plans can be found at: http://www.epa.gov/opptintr/pbt/
[67] The list of chemicals identified by the OSPAR Commission for priority action can be found at: http://www.ospar.org/eng/html/
[68] The USEPA NPEP list can be found at: http://www.epa.gov/epaoswer/hazwaste/minimize/chemlist.htm

Appendix 2 (continued) - Chemicals Targeted for Elimination / Reduction by the Stockholm Convention, US EPA and OSPAR

Mercury and organic mercury compounds		X	X	X
Methoxychlor (pesticide/biocide)			X	X
Mirex	X	X		
Musk xylene			X	
Naphthalene				X
Neodecanoic acid, ethenyl ester (organic ester)			X	
Nonylphenol/ ethoxylates (NP/NPEs) and related substances (phenol)			X	
Octachlorostyrene (OCS)		X		
octylphenol (phenol)			X	
organic tin compounds			X	
Pendimthalin				X
Pentachlorobenzene				X
Pentachloronitrobenzene				X
Pentachlorophenol (PCP) (pesticide/biocide)			X	X
Perfluorooctanyl sulphonic acid and its salts (PFOS)			X	
Phenanthrene				X
Phthalates: Dibutyl phthalate (DBP), diethylhexyl phthalate (DEHP)			X	
Polyaromatic hydrocarbons (PAHs)			X	X
Polychlorinated biphenyls (PCBs)	X	X	X	X
Polychlorinated dibenzodioxins (PCDDs)	X	X	X	X
Polychlorinated dibenzofurans (PCDFs)	X	X	X	X
Pyrene				X
Short chained chlorinated paraffins (SCCP)			X	
Toxaphene	X	X		
Trifluralin (pesticide/biocide)			X	X
Triphenyl phosphine (organophosphate)			X	
Total # of Chemicals Listed	**12**	**14**	**32**	**31**

Bold rows are chemicals that are evaluated in pipes in this assessment

Appendix 3 - Priority Chemicals of Highest Concern in Outputs

Lifecycle Stages	Stockholm Convention POPs				US EPA PBTs				OSPAR + US EPA Priority Chemicals			
	PVC	ABS	HDPE & PEX	PP	PVC	ABS	HDPE & PEX	PP	PVC	ABS	HDPE & PEX	PP
-- Initial raw material extraction and processing ----								na = not applicable to this plastic Blank cells = no data collected for this topic				
Brine extraction	No data		na		No data		na		No data		na	
Natural gas / oil extraction	Water effluent: furans				Water effluent: furans, lead and mercury				Water effluent: cadmium, DEHP, furans, lead, mercury, PAHs, pentachlorophenol			
Natural gas processing	none				none				none			
Crude oil refining	Air emissions: dioxins**; Water effluent; raw: aldrin, DDT				Air emissions: dioxins, benzo(a)pyrene; Water effluent, treated: benzo(a)pyrene, lead, mercury; Water effluent, raw: aldrin, DDT				Air emissions: dioxins; Water effluent; treated: cadmium, DBP, PAHs; pentachlorophenol			
Chlorine production	Byproducts: furans, PCBs, hexachlorobenzene		na		Mercury** ; Water effluent; treated: lead, Octachlorostyrene	na	na		Mercury; Water effluent; treated: lead; Water effluent, untreated: cadmium	na	na	
na = not applicable * from petroleum refining catalyst regeneration ** from the mercury cell diaphragm process												
-- Feedstock, Resin, Polymer, and Product Production ----												
Acrylonitrile production	na	No data	na	na	na	No data	na	na	na	No data	na	na
Benzene production	na	none	na	na	na	Water effluent; treated: benzo(a)pyrene, lead, mercury	na	na	na	Water effluent; treated: cadmium, DEHP, lead, mercury, PAHs	na	na
1,3 butadiene		No data	na			No data	na			No data	na	

Appendix 3 - Priority Chemicals of Highest Concern in Outputs (continued – 2 of 3)

Lifecycle Stages	Stockholm Convention POPs				US EPA PBTs				OSPAR + US EPA Priority Chemicals			
	PVC	ABS	HDPE & PEX	PP	PVC	ABS	HDPE & PEX	PP	PVC	ABS	HDPE & PEX	PP
— Feedstock, Resin, Polymer, and Product Production (cont) ——												
Styrene Production	na	none	na	na	na	Water effluent, treated: **benzo(a)pyrene**		na	na	Water effluent, treated: **PAHs**		na
Ethylene production		none		na	Water effluent, treated: **benzo(a)pyrene, mercury**			na	Water effluent, treated: **DEHP, mercury, PAHs, cadmium**		na	
Propylene production			none			na		Water effluent, treated: **benzo(a) pyrene, mercury**		na		Water effluent, treated: **DEHP, mercury, PAHs, cadmium**
Ethylene dichloride (EDC) and vinyl chloride monomer (VCM) production	Byproduct: **dioxins, furans, PCBs, hexachlor obenzene**		na		Byproduct: **dioxins, furans, PCBs**		na		Byproduct: **dioxins, furans, PCBs, hexa- chlorobe nzene**; Water effluent, treated: **DEHP, DBP, penta- chloroph enol**		na	

Appendix 3 - Priority Chemicals of Highest Concern in Outputs (continued - 3 of 3)

Lifecycle Stages	Stockholm Convention POPs				US EPA PBTs				OSPAR + US EPA Priority Chemicals			
	PVC	ABS	HDPE & PEX	PP	PVC	ABS	HDPE & PEX	PP	PVC	ABS	HDPE & PEX	PP
-- Feedstock, Resin, Polymer, and Product Production (cont – polymerization & compounding												
ABS poly-merization & compounding	na	No data	na	na	na	No data	na	na	na	No data		na
HDPE poly-merization & compounding	na	na	none	na		na	none	na	na	na	Water effluent, treated: PAHs	na
PP poly-merization & com-pounding		na	none	none		na	none	none		na		Water effluent, treated: DEHP, PAHs
PVC poly-merization & com-pounding	none	na	na		none		na		Lead, organotin compounds		na	
-- Product Use --												
Accidental fires	dioxins / furans ++	none			dioxins / furans		No data		dioxins / furans	No data	No data	
Normal use of Pipe		none					none		organotin or lead com-pounds	No data	No data	
-- End of Life --												
Landfill disposal	dioxins / furans +	none			dioxins / furans		No data		dioxins / furans	No data	No data	
Incinerator disposal	dioxins / furans++	none			dioxins / furans		No data		dioxins / furans	No data	No data	

na = not applicable to this plastic   No data = no data collected for this topic   none = none of these chemicals have been measured for this stage of this plastic

+ from landfill fires   ++ chlorine is necessary for dioxin formation

Sources: Assessing the impacts of production and disposal of packaging and public policy measures to alter its mix (volume II). Boston: Tellus Institute. 1992
Thornton, Joe, PhD., Pandora's Poison. Cambridge, MIT Press. 2000

Appendix 4 - Average Composition of PVC Sewer Pipes

Inputs	Entec UK Ltd, 2000 (%)	Intron Report #95027 (%)
PVC	92.1	94
Stabilizers		
- tribasic lead sulphate	1.4	
- dibasic lead stearate	0.5	
- lead stearate	0.2	1.1
- lead stearate	0.4	
- lead stailizer		
- tin stabilizer		
Plasticizer		
Filler		3.8
- powdered limestone	4.7	
Stearic acid	0.1	
Synthetic hard wax	0.1	
Paraffin (lubricant)		0.7
Pigment		
- carbon black	0.5	0.2
- titanium dioxide		0.2
Total	100	100

Source: Baitx, Martin, et. al. 2004. Life Cycle Assessment of PVC and of Principal Competing Materials. Brussels: European Commission.

Appendix 5 - Additives that may be Used with Plastic Pipes

	PVC	ABS	PEX	HDPE	PP
Antioxidants					
		0.1-1.0% by weight of polymer resin		0.15% by weight of polymer resin	0.05-0.25% by weight of polymer resin
		-- Phenolics	-- Phenolics	-- Phenolics	-- Phenolics
	-- Phosphites	-- Phosphites and phosphonites	-- Phosphites	-- Phosphites	-- Phosphites and phosphonites
		-- Thioesters			-- Thioesters
Antistatic agents					
	--	-- Ethoxylated amines	-- Ethoxylated amines	-- Ethoxylated amines	-- Ethoxylated amines
	-- Fatty acid ester		-- Fatty acid ester	-- Fatty acid ester	-- Fatty acid ester
	-- Alkylsufonate	-- Alkylsufonate			
	-- Quaternary ammonium compounds				
Lubricants					
	-- Calcium stearate	-- Zinc stearate	-- Zinc stearates	-- Zinc stearates	-- Zinc stearates
	--	-- Fatty acid amides	-- Fatty acid amides	-- Fatty acid amides	-- Fatty acid amides
	-- Fatty acids and fatty esters		-- Fatty acids	-- Fatty acids	-- Fatty acids
	-- Hydrocarbon waxes: paraffins				
UV light stabilizers					
	-- Carbon black	-- Carbon black	-- Carbon black	-- Carbon black	-- Carbon black
		-- Benzophenones			-- Benzophenones
		-- Hindered amine light stabilizers (HALS)			-- Hindered amine light stabilizers (HALS)
Stabilizers					
	- Lead-based stabilizers	-- na	-- na	-- na	-- na
	-- Organotins				
	-- Cadmium**				
	-- Calcium-zinc				
"na" = not applicable					

Sources:
- Modler, Robert, Eric Anderson, and Yosuke Ishikawa. Chemical Economics Handbook, "Plastics Additives," Palo Alto, CA: SRI International. 1997.
- The Plastics Pipe Institute. 1999. Weatherability of Thermoplastic Piping Systems. Washington, DC: The Plastics Pipe Institute.
- Zweifel, Hans (ed.). 2000. Plastics Additives Handbook (5th Edition). Munich: Hanser Publications
- Special Chem database, www.specialchem4polymers.com/resources/search

Appendix 6 - Toxicity of Inputs

Plastics	Chemical Inputs	Carcinogens (multiple lists)	Mutagens (EU CMR List)	Reproductive / Developmental Toxicants (EU CMR List + CA Prop 65)	Endocrine Disruptors (EU Draft List)	Persist-ence (EU List)	Bio-accumul ative Capacity (EU List)
ABS	Acrylonitrile	I-2B, N-2, CP65, EU-2					
ABS	Alkylsulfonate (antistatic)	*Need to know the specific chemicals used. But toxicity data are likely to be absent. For example, no toxicity data have been evaluated for "sodium dodecylbenzene sulfonate-iodine complex" (CAS# 53467-01-9) (Pesticides Action Network, "Pesticides Database - Chemicals," 2004).*					
ABS, HDPE, PEX, PP	Fatty acid amides (lubricant)	*Need to know specific chemical. But toxicity data are likely to be absent. For example, no toxicity data have been evaluated for "diethanolamides of the fatty acids of coconut oil" (RTECS, 2003).*					
ABS	Benzene	I-1, N-1, CP65, EU-1		CP65			
ABS, PP	Benzo-phenones	*Need to know the specific chemical used. For example, bis(dimethyl-amino) benzophenone is a NTP-2 and CP65 carcinogen.*					
ABS	Butadiene, 1-3	I-2A, N-1, CP65, EU-1	EU-2	CP65			
PVC	Cadmium (Cd) Compounds	I-1, N-1, CP65, EU-2	EU-2 (selected Cd compounds) [CP65 - Cd, yes; Cd compounds, no]	EU Category 2 (selected Cd compounds)		Metal	
PVC	Chlorine						
ABS, HDPE, PEX, PP, PVC	Carbon Black	I-2B, CP65					
ABS, HDPE, PP	Ethoxylated amine (antistatic)	*Need to know specific chemical. But toxicity data are likely to be absent. For example, no toxicity data have been evaluated for "amines, tallow, ethoxylated, carboxylated" (CAS#: 61791-25-1) (RTECS, 1999).*					
ABS	Ethylbenzene	I-2B	-				
ABS, HDPE, PEX, PVC	Ethylene						
PVC	Ethylene Dichloride (EDC)	I-2B, N-2, CP65, EU-2					
HDPE, PEX, PP	Fatty acids and esters (antistatic + lubricant)	*Need to know specific chemical. But toxicity data are likely to be absent. For example, no toxicity data have been evaluated for "fatty acids, coconut oil, sulfoethyl esters, sodium salts" (CAS# 61789-32-0) (RTECS, 1997).*					
ABS, PP	Hindered amine light stabilizers (HALS)	*The US EPA, TSCA New Chemicals Program, concluded in 2001 that the category "Hindered Amines" is "at present not well defined." Health concerns for the category, according to the EPA are based on data submitted for Tinuvin 144 and Chimassorb 944: "The data indicate that these hindered amines, and presumably hindered amines similar in structure, are toxic to the immune system, liver, blood, the male reproductive system, and the G.I. tract" (US EPA, 2001). However, HALS are not listed by either the EU or Prop 65 as reproductive/developmental toxicants.*					
PVC	Lead Compounds	I-2B, CP65		EU-1 (selected lead com-pounds); [CP65 - lead, only no compounds		Metal	

Plastics	Chemical Inputs	Carcinogens (multiple lists)	Mutagens (EU CMR List)	Reproductive / Developmental Toxicants (EU CMR List + CA Prop 65)	Endocrine Disruptors (EU Draft List)	Persist-ence (EU List)	Bio-accumulative Capacity (EU List)
PVC	Organotins				EU-1	Metal	
PVC	Paraffin (lubricant)	Limited carcinogenicity studies have been done on paraffin (CAS# 8002-74-2) fumes, but none of the lists assessed here include paraffin as a carcinogen.					
ABS, HDPE, PEX, PP	Phenolics (antioxidant)	Need to know the specific chemical used. For example Bisphenol A (CAS #: 80-05-7) is a Category 1 endocrine disruptor in the EU.					
ABS, HDPE, PEX, PP	Phosphites (antioxidant)	Need to know specific chemical. But toxicity data likely to be absent. For example, no chronic toxicity data are available for "bis(2-ethylhexyl) phosphite" (CAS#: 3658-48-8) (RTECS, 1997).					
PP	Propylene						
PVC	Quaternary ammonium compounds	No chronic toxicity data available (RTECS, 2003), yet there is evidence that these compounds can cause occupational asthma (Purohit, et al., 2000)					
ABS	Styrene Monomer	I-2B			EU-1		
ABS, PP	Thioesters (antioxidants)	Need to know specific chemical. But toxicity data likely to be absent. E.g., no chronic toxicity data available for "methyl demeton thioester" (CAS#: 919-86-8) (RTECS, 1997).					
PVC	Vinyl Chloride Monomer(VCM)	I-1, N-1, CP65, EU-1					
ABS, HDPE, PEX, PP	Zinc stearate (lubricant)						

"Blank cells" = no data found for that endpoint

Carcinogen abbreviations
     "I": International Agency for Research on Cancer (World Health Organization)
          I-1: Carcinogenic to humans
          2A: Probably carcinogenic to humans
          2B: Possibly carcinogenic to humans

     "N": National Toxicology Program (Health and Human Services Dept., Public Health Service, NIH/NIEHS
          1: Known to be carcinogenic
          2: Reasonably anticipated to be carcinogens

     "CP65": California Proposition 65 - Chemicals Known to the State to Cause Cancer
     "EU": European Union Consolidated List of C/M/R Substances
          1: Category 1
          2: Category 2
Mutagens
     "EU CMR List": European Union Consolidated List of C/M/R [Carcinogen/Mutagen/Reproductive toxicant] Substances"
Reproductive / Developmental Toxicants
     "EU CMR List": European Union Consolidated List of C/M/R Substances"
     "CP65": California Proposition 65 - Chemicals known to the state to be developmental / reproductive toxicants
Endocrine Disruptors
     European Union (EU) "Candidate List of Substances" (2000)
          "EU-1": Category 1: At least one study providing evidence of endocrine disruption
          "EU-2": Category 2: Potential for endocrine disruption
Persistence & Bioaccumulative Capacity
     Swedish National Chemicals Inspectorate (Keml)

Appendix 7 - Performance Comparison of Pipe Plastics

Comparative Technical Data for the Pipe Plastics [69]								
Type of Plastic	Density, g/cm³ (ASTM D 792)	Coefficient of Thermal Expansion, 10⁻⁶/°C (ASTM D 696)	Tensile Strength, (psi) (ASTM D 638)	Compressive Strength, (psi) (ASTM D 695)	Temperature Limits (F) Pressure applications	Temperature Limits (F) Non pressure applications	Flexural Strength, (psi) (ASTM D 790)	Modulus of Elasticity, (10⁵·psi) (ASTM D 638)
PVC	1.38	50	7,000	9,600	158	179 (210 CPVC)	14,500	4.5
HDPE	0.95	130	2,800	3600	140	194	2,000	0.20
ABS	1.04	101	5,500	7,700	158	176	10,000	3.1
PEX[70]	0.95	141	3,900		210	210[71]	15,000	1.5
PP	0.91	68	4,900	8,500	180	194	8,500	1.5

The following tables provide an overview of important design and operational considerations for the plastics in various pipe sectors:

Water and Pressure Sanitary					
	PVC	ABS*	PEX	HDPE	PP**
Durability	G	N/A	G	G	G
Joint integrity	G	N/A	E	E	E
Pressure rating		N/A	G	G	G
Abrasion resistance	G	N/A	E	E	E
Chemical resistance	G	N/A	No data	E	E

*ABS is not generally used for pressure applications.
** PP is widely available in Europe, but just beginning to be marketed in North America.

DWV					
	PVC	ABS	PEX*	HDPE**	PP**
Durability	G	G	N/A	G	G
Joint integrity	G	G	N/A	E	E
Pressure rating	G	P	N/A	G	G
Abrasion resistance	G	No data	N/A	E	No data
Chemical resistance	G	G	N/A	E	E

* The flexibility and other considerations preclude the use of PEX for use in this sector.
**HDPE is not generally used for this application. PP is just beginning to be marketed in North America

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[69] [69] National Resource Council of Canada website http://irc.nrc-cnrc.gc.ca/cbd/cbd220e.html
[69] http://www.vanguard.ca/products/canplumb.pdf
[69] Suggested Temperature Limits for the Operation and Installation of Thermoplastic Piping in Non-Pressure Applications TN-11/99 http://www.plasticpipe.org/pdf/pubs/notes/TN11-99.PDF
[70] Vanguard pipes http://www.vanguard.ca/products/canplumb.pdf
[71] Suggested Temperature Limits for the Operation and Installation of Thermoplastic Piping in Non-Pressure Applications TN-11/99 http://www.plasticpipe.org/pdf/pubs/notes/TN11-99.PDF

Sanitary Sewer (Gravity)

	PVC	ABS	PEX*	HDPE	PP**
Durability	G	G	N/A	G	G
Joint integrity	G	G	N/A	G	G
Pressure rating	G	P	N/A	G	G
Abrasion resistance	G	No data	N/A	E	E
Chemical resistance	G	G	N/A	E	E

* The flexibility and other considerations preclude the use of PEX for Sanitary Sewer.
** PP sanitary pipe is widely available in Europe but just beginning to be marketed in North America

Storm Sewer

	PVC	ABS*	PEX**	HDPE	PP***
Durability	G	N/A	N/A	G	G
Joint integrity	G	N/A	N/A	E	E
Pressure rating	G	N/A	N/A	G	G
Abrasion resistance	G	N/A	N/A	E	E
Chemical resistance	G	N/A	N/A	E	E

*ABS is not generally available for Storm Sewer Applications. T
** The flexibility and other considerations preclude the use of PEX for Storm Sewer.
*** PP is generally not marketed for storm sewer applications.

Irrigation and Drainage

	PVC	ABS **	PEX*	HDPE	PP***
Durability	G	G	N/A	G	G
Joint integrity	G	G	N/A	E	E
Pressure rating	G	P	N/A	G	G
Abrasion resistance	G	No data	N/A	E	No data
Chemical resistance	G	G	N/A	E	E

* The flexibility and other considerations preclude the use of PEX for use in this sector.
**ABS is generally not used for irrigation and drainage applications
*** While PP is frequently used for fittings in this market it is not typically used for irrigation or drainage pipes

As these tables demonstrate, ABS and PEX have particular niche markets and the rest of the plastics are competitive across applications from a performance perspective.

References for rankings in tables:

- o Chemical resistance: http://irc.nrc-cnrc.gc.ca/cbd/cbd220e.html   reference for
- o Abrasion and chemical resistance http://www.cheresources.com/plpipezz.shtml
- o Joint integrity and durability and chemical resistance and abrasion
  http://www.on.ec.gc.ca/water/greatlakes/data/chlor-alkali

Appendix 8 - Glossary of Abbreviations

ABS	Acrylonitrile-butadiene-styrene
ASTM	American Society for Testing and Materials
Cd	Cadmium
CMR	Carcinogen, mutagen or reproductive toxicant
CPVC	Crosslinked polyvinyl chloride
DBP	Dibutyl phthalate
DEHP	Di(2-ethylhexyl) phthalate
DWV	Drain-waste and vent
EDC	Ethylene dichloride
EU	European Union
HDPE	High density polyethylene
Hg	Mercury
IARC	International Agency for Research on Cancer
LCA	Life Cycle Assessment
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North East Atlantic
PAH	Polyaromatic hydrocarbon
Pb	Lead
PBT	Persistent Bioaccumulative Toxic
PCB	Polychlorinated biphenyls
PCP	Pentachloro-phenol
PET or PETE	Polyethylene terephthalate
PEX	Cross linked polyethylene
POP	Persistent organic pollutant
PP	Polypropylene
PVC	Polyvinyl chloride
Stockholm	Stockholm Convention on Persistent Organic Pollutants
TRI	Toxic Release Inventory (US EPA)
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VCM	vinyl chloride monomer

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About CEH

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Healthcare
without Harm

Technical
Assistance to
Communities

Our Mission

The Center for Environmental Health protects the public from environmental and consumer health
hazards. We are committed to environmental justice, reducing the use of toxic chemicals,
supporting communities in their quest for a safer environment, and corporate accountability. We
change corporate behavior through education, litigation, and advocacy.

Public Policy

Industry
Change

Programs

Soon to Come

CEH Board of Directors

Julie Parker Benello, Film Producer

Julie produces documentaries on health and environmental issues for television. She co-
produced the Sundance award winning HBO documentary BLUE VINYL a film in search of the
truth about vinyl (PVC), America's most popular plastic. Previously she produced a film for PBS
entitled Prostate Cancer: A Journey of Hope. Julie also serves on the board of the Clarence
Foundation and Working Films.

André Carothers, Rockwood Fund

André is the Executive Director of the Rockwood Leadership Program, a non-profit organization
that provides consulting and leadership training to activists and senior managers of organizations
advocating for the environment, human rights, and social and economic justice. André also serves
on the board of directors of the Rainforest Action Network.

Antonio Diaz, PODER

Antonio is the Executive Director of PODER (People Organized for the Defense of Environmental
Rights), a community-based organization in San Francisco's Mission District working to. He is a
nationally known leader in the environmental justice community and is an Advisory Board Member
of Corpwatch.

Michael Dorsey, Dartmouth College, Environmental Studies

Michael is the Thurgood Marshall visiting lecturer at Dartmouth College. He is a National Board
Member of the Sierra Club, a Task Force Member of the Environmental Leadership Program and

an Advisory Board Member of CorpWatch. In addition, he is a trustee and founding member of the Environmental Leadership Program, a former National Advisory Board Member for Youth Warriors, and a former Board Member of Edmonds Institute.

Kathy Gerwig, Kaiser Permanente

Kathy is Vice-President for Work Place Safety at Kaiser-Permenente. Previously, Kathy was the director of Environmental Stewardship, and responsible for developing, organizing and managing a nationwide environmental initiative for Kaiser Permanente. She is a visionary leader in moving industry away from the use of toxic chemicals, and is on the Board of Directors of Health Care Without Harm.

Karleen Lloyd, Oakland, CA

Karleen was the Lead Organizer at People United for a Better Oakland (PUEBLO), a community-based organization dedicated to improving health care, education, and neighborhood safety for all Oakland residents. She is a well-known leader in the environmental justice movement.

Anuja Mendiratta, Marin Community Foundation

Anuja is the Program Officer for Community Development at the Marin Community Foundation. Previously, she coordinated the San Francisco Foundation's Environmental Health and Justice Initiative, and worked as a researcher with FoodShare, an organization dedicated to promoting food security in Toronto, Canada. She currently also serves on the boards of the La Pena Cultural Center and the Community Toolbox for Children's Environmental Health and is a policy fellow with the Women's Foundation of California.

Marni Rosen, Board Chair, Jenifer Altman Foundation

Marni is Executive Director of the Jennifer Altman Foundation, Administrator of the Mitchell Kapor Foundation, and advisor to the StarFire Fund. Prior to joining these foundations, she was the Associate Director of The Children's Environmental Health Network, served as the NGO Liaison for a United Nations conference, and conducted public health research in New York on HIV/AIDS issues.

Lawrence Smith, Smith and Company, CPA's

Lawrence is the founder and principle chair at Smith and Company CPAs. He provides fiscal and managerial oversight to CEH's operations. He is the longest serving member of the CEH Board, joining in early 1997.

Francesca Vietor, Environmentalist

Francesca has worked for several non-profit organizations, including Rainforest Action Network, Greenpeace, Island Press, and CARE Madagascar. Recently, she served as the Director of the San Francisco Department of the Environment. Currently, she is a Senior Research Associate with the Health and Environment Program at Commonweal in Bolinas, California.

Katie Silberman

Katie works on reducing communities' exposure to toxics through policy, advocacy and activism. The first Ralph S. Abascal Fellow at the University of California, Hastings College of the Law, Katie brought her Fellowship to CEH in 2000. Prior to joining CEH, she worked on issues of health and environmental justice in the Bay Area with such organizations as Breast Cancer Action, Communities for a Better Environment and the Center on Race, Poverty and the Environment.

CEH Staff

Lara Cushing, Research Director

As the manager of CEH's Public Interest Litigation Program, Lara researches corporations that illegally expose people to toxic chemicals that cause disease. She has a Bachelors degree in Molecular Environmental Biology from UC Berkeley, where she focused on global climate change and restoration ecology.

Michael Green, Executive Director

Michael founded the Center for Environmental Health (CEH) in 1996 after leaving the US Department of Energy's Office of Environmental Management in Washington, D.C. As Director of CEH, he has been a leader in national efforts to stop toxic exposures and protect public health, and developed the groundbreaking CEH legal work that has won major victories in holding industries accountable for hazardous consumer products and toxic emissions. He has worked with the U.S. EPA Working Group on Environmental Equity, the Tibetan refugee community in Dharamsala, India, Mother Teresa in Calcutta, India, and the legal advisor to His Holiness the Dalai Lama in The Netherlands. He has been interviewed for national news reports by the Wall Street Journal, New York Times, Washington Post, Toronot Globe & Mail, CBS Evening News, Good Housekeeping, and NPR Marketplace, as well as several international news media outlets. He serves on the board of directors for the Tibet Justice Center, Environmental Justice and Health Union, and the California League for Environmental Enforcement Now.

Anjuli Gupta, Community Health and Environment Project Coordinator

Ani has worked on environmental health and justice issues in the Bay Area for three years. Ani previously interned with CEH while an undergraduate at Berkeley, and completed a senior research project on medical waste management in the Bay Area. Most recently, she staffed the Environmental Justice and Climate Change Initiative at Redefining Progress.

Joe Guth, Senior Policy Analyst

Joe has left his position as Vice President of the Chiron Corporation, one of the world's leading biotechnology companies, to join CEH. Previous to his biotechnology work, he was a Senior Project Attorney for the New York branch of the Natural Resources Defense Council. At CEH, Joe will work to ensure strong environmental health policy at the local and state level.

PJ Johnson, Financial and Administrative Manager

PJ is a graduate of UC Santa Cruz with degrees in Community Studies (LGBT focus) and Theater Arts (Modern Dance focus). While in Santa Cruz, he worked with at-risk youth at Above The Line – Group Home Society and interned for the LGBT organization Triangle Speakers. After reading The Last Hours of Ancient Sunlight by Thom Hartmann, PJ's social change interests shifted towards sustainable ecology issues. He sees sustainable ecology as vital to the success of any other issue, be it human rights or national security.

Mamta Khanna, Pollution Prevention Program Manager

Mamta has several years experience working on medical waste and pollution prevention, including co-founding the Mumbai Medwaste Action Group in Mumbai, India. At CEH, her work includes collaborating with the healthcare industry and the design and construction industries to educate and enlist them to use less toxic alternative materials, products and practices.

Charles Margulis, Food Program Director

Charles was previously a Genetic Engineering Campaigner for Greenpeace, and has worked in fundraising for Peace Action and PIRG. He is a graduate of the University of California at Berkeley in Peace and Conflict Studies. He is also a graduate of the California Culinary Academy and is a long-time professional baker.

Joanna Mattson, Toxics Researcher

Joanna is a graduate of UC Santa Cruz with a degree in Politics and pre-medical studies. After taking post-baccalaureate classes in chemistry at San Francisco State University, she became dedicated to non-profit environmental work, taking a special interest in exposure assessment and environmental epidemiology.

Basmah Mourad, Development Manager

Basmah has joined CEH after graduating with honors from UC Santa Cruz with an Environmental Studies degree and a minor in Legal Studies. She recently completed an internship for the Development Review Commission in Micronesia, where she did work on biodiversity and sustainability. She has experience in grant-writing, organizing, fundraising, and event planning.

CEH Fall 2004 Work Study & Interns

Work Study

Sara Bergman, Accounting and Administrative Assistant

Sara provides administrative and financial support to CEH staff. She is currently a student at UC Berkeley studying Development Studies. She is working at CEH through the university's work-study program.

Anita Sara Jackson, Pollution Prevention Program Associate

Anita Sarah Jackson is a May 2003 graduate of American University's Washington College of Law, where she focused on health and human rights. Anita was a legal and policy intern for CEH's Policy Program in the spring of 2004. She recently completed a five month foundation-funded Health Care Without Harm Fellowship in the Pollution Prevention Program. Anita will continue to work on Pollution Prevention issues as a part time staff member beginning in the winter of 2005.

Summer 2005 Interns

Banafsheh Amini, Prop 65 Intern

Banafsheh is a third year Integrative Biology and Public Health major at UC Berkeley. She works for Sylvan Education Solutions to tutor children in local public schools and is actively involved in Rotaract, an international community service organization on campus. Banafsheh also writes and edits for Perspective Magazine, an independent, student-run publication that deals with political, health, and social issues concerning the Iranian-American community. Banafsheh hopes to attend law school and focus on health and bioethical issues.

Tendai Chitewere, Pollution Prevention and Development Intern

Originally from Zimbabwe, Tendai is a socio-cultural applied anthropologist, is completing her dissertation on an ecovillage where she explores consumption and environmentalism. In addition to having a foot in academia, she has held many jobs in university administration including the assistant director for affirmative action and the coordinator of the peer education program at SUNY Binghamton. In her spare time she enjoys cooking and is currently training for her first triathlon.

Ian Goldstein, Development Intern

Ian is a junior at Colorado College, a small liberal arts school in Colorado Springs. Out of the classroom, Ian is involved in a wide range of activities, including heading up a campus organic food cooperative, working to bring organic fair trade coffee to campus coffee shops, and designing and maintaining a website for his school's student environmental organization. In his free time, Ian sings in an all-male acappella singing ensemble, which he founded and currently directs, manages group finances, and writes grants. He is excited to spend his summer in the Bay Area working for the Center for Environmental Health.

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AFR

April 18, 2005
Lucetta Dunn
Director, California Department of Housing and Community Development
1800 Third Street
P.O. Box 952050
Sacramento, CA 94252-2050
Re: Approval of CPVC (State Clearinghouse No. 2000091089) - Oppose

Dear Ms. Dunn,

On behalf of the San Francisco Bay Area Chapter of Physicians for Social Responsibility (SF PSR), with approximately 2,000 physician and other health care professional members, I am writing to express our opposition to the proposal of the Department of Housing and Community Development (HCD) to approve chlorinated polyvinyl chloride (CPVC) drinking water pipe for statewide use in residential buildings (State Clearinghouse No. 2000091089). SF PSR is one of the leading organizations in Northern California providing scientifically credible advocacy on environmental health issues. Protecting the public's health is our mission.

It has come to our attention that the HCD is putting forth this proposal, which would require all cities and local jurisdictions in California to allow the use of CPVC in any residential building, without the review of a comprehensive environmental impact report (EIR). A study recently released from the San Francisco Department of the Environment concluded that CPVC pipe should be avoided for use in water systems because it generates highly toxic chemicals that can leach into drinking water, that it is very difficult to recycle and that it adds to the burdens on landfills.

Given the potential public health and environmental implications of this material and its use in water systems, we urge you to consider having a full EIR prepared for your review before making such a decision as that which is outlined in this proposal and to consider alternatives to the CPVC as acceptable pipe material that could be used. Thank you for your attention to this. The public's health and the preservation of our environment require this kind of scrutiny in place when such important, far-reaching decisions are made.

Sincerely,

Robert M. Gould, M.D.
President
San Francisco Bay Area PSR

PVC

Bad News Comes in ♳s

The Poison Plastic, Health Hazards and the Looming Waste Crisis

PVC

Bad News Comes in ⟨3⟩s

The Poison Plastic, Health Hazards and the Looming Waste Crisis

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ACKNOWLEDGEMENTS

Keeping the American Promise:

Achieve Safer and Healthier Future
By Eliminating PVC, The Poison Plastic

Dear Friends,

This report provides the facts and a plan of action for one of the most important changes society can make to protect the public's health and the environment.

PVC is a poison plastic. It has earned the title after decades of harming our health and environment. PVC's destructive toxic life begins with manufacturing, continues during product use, and then creates devastating pollution problems when it is disposed. I cannot think of another product that is so destructive throughout its entire life cycle as PVC.

In Louisiana, families gather to talk about how growing health problems in their neighborhood are connected to the local plastic chemical plant's emissions. In Massachusetts, families meet to discuss the rising cancer rates in their valley and the nearby incinerators burning large amounts of PVC and releasing dioxin into the air.

I have traveled across the nation visiting neighborhoods that confront the hazards from manufacturing or disposing of PVC plastics every day. These American families find their homes are suddenly worthless and they are trapped in a nightmare of frustration—trying to prove the pollution from the plant or incinerator has caused the damage to their health. Many of these community stories are briefly described in this report.

Our country's fire fighters and first responders are worried about exposures to PVC's toxic fumes every time they encounter a fire. Consumers are concerned about vinyl plastic tablecloths or shower curtains that release toxic fumes, often referred to as "that new smell." Parents are worried about the leaching of toxic chemicals from PVC toys that their children used in the past.

The sad truth behind the destruction and harm caused by PVC, is that in most cases it is not needed. There are plenty of alternatives that are readily available on the market today. On store shelves, consumers can choose shampoo with a PVC bottle (marked with a #3 or V in the recycle symbol triangle) or a safer PVC-free plastic bottle. A growing number of responsible corporations have decided to stop using PVC. Irresponsible corporations, on the other hand, have refused to move to safer plastics.

An important part of this report is the well-documented fact that there is no "away" for PVC. There is no way to get rid of the product once manufactured. It is with us forever—a legacy left to the next generation. You can't burn it—it just changes to dioxin, another very toxic pollutant. You can't bury it—chemicals leak out into the surrounding soil and groundwater. You can't recycle it—it contaminates the recycling process.

This report gives us hope by outlining how we as a society can phase out PVC in the future, with clear models to begin that phase out now. You'll learn in this document about the many safer, affordable alternatives to PVC that are available today.

We need to begin a nationwide conversation, community by community, on how to phase out PVC. As consumers we need to send a strong message to corporations who are resisting the effort to eliminate PVC and let them know we will not purchase their products. We need to encourage companies to use their entrepreneurial ingenuity to develop new products without PVC, the poison plastic. And, we need to enlist all levels of government to pass strong policies to phase-out PVC.

We must move quickly. Generating as much as seven billion pounds of PVC waste each year cannot continue. We can't bury it, burn it or recycle it. PVC wastes will live beyond the lifetime of everybody on this planet—a terrible legacy to leave for future generations.

A road map for how society can eliminate PVC is included in this report. If everyone takes a step down this road we can achieve a phase-out and begin to safeguard public health and the environment. I hope you will join us and help to leave our children a healthier, more sustainable world.

Lois Marie Gibbs
Executive Director
Center for Health, Environment and Justice

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SUMMARY

"Billions of pounds of PVC, the 'poison plastic,' are being thrown 'away' in the U.S.— but there is no away for the health threatening chemicals associated with PVC."

The disposal of polyvinyl chloride (PVC) plastic threatens public health and the environment. Although problematic throughout its lifecycle – from production through final use – the discarding of PVC as waste poses perpetual hazards. PVC is widely used in plastic pipes, building materials (e.g., vinyl siding, windows), consumer products, disposable packaging and many everyday products. We can prevent harm from PVC by replacing it with safer, cost-effective alternatives that are available, and by diverting PVC waste away from incineration and open burning. This report summarizes data on PVC production, use and disposal in the United States, though its conclusions about the environmental health hazards of PVC are applicable to every country.

How much PVC do we use?

Billions of Pounds of PVC are Discarded Each Year

Large and growing amounts of PVC are discarded daily in the U.S. As much as 7 billion pounds of PVC is discarded every year in municipal solid waste, medical waste, and construction and demolition debris. PVC disposal is the largest source of dioxin-forming chlorine and hazardous phthalates in solid waste, as well as a major source of lead, cadmium and organotins. Dioxins are a family of highly toxic chemicals that are known to cause cancer, reproductive, developmental and immune problems. More than 2 billion pounds per year of nondurable (short-lived) PVC products are discarded with U.S. household trash, including blister packs and other packaging, plastic bottles and containers, plastic wrap and bags, and more. In fact, nondurable products account for more than 70% of the PVC disposed of in U.S. municipal solid waste. Worldwide, an estimated 300 billion pounds of PVC, which was installed in the last 30 to 40 years in construction and other long lasting uses, will soon reach the end of its useful life and require disposal.

What's so bad about PVC plastic?

PVC: A Truly "Poison" Plastic
Unlike the many plastics made without chlorine, PVC

poses serious environmental health threats from the start. The production of PVC requires the manufacture of raw chemicals, including highly polluting chlorine, and cancer-causing vinyl chloride monomer (VCM) and ethylene dichloride (EDC). Communities surrounding U.S. vinyl chloride chemical facilities, half of which are in Louisiana, suffer from serious toxic chemical pollution of their groundwater supplies, surface waters and air. Residents of the town of Mossville, Louisiana had dioxin levels in their blood that were three times higher than normal. PVC plastic also requires large amounts of toxic additives to make it stable and usable. These additives are released during the use (and disposal) of PVC products, resulting in elevated human exposures to phthalates, lead, cadmium, tin and other toxic chemicals. Dioxin emissions from PVC combustion occur regularly due to the 1 million annual fires that burn buildings and vehicles, two sectors that use substantial amounts of PVC.

What are the options for disposing of used PVC?

PVC Products + Waste Incinerators or Open Burning = Dioxin Emissions

Dioxin formation is the Achilles heel of PVC. Burning PVC plastic, which contains 57% chlorine when pure, forms dioxins, a highly toxic group of chemicals that build up in the food chain. PVC is the major contributor of chlorine to four combustion sources—municipal solid waste incinerators, backyard burn barrels, medical waste incinerators and secondary copper smelters—that account for a significant portion of dioxin air emissions. In the most recent USEPA Inventory of Sources of Dioxin in the United States, these four sources accounted for more than 80% of dioxin emissions to air based on data collected in 1995. Since then, the closure of many incinerators and tighter regulations have reduced dioxin air emissions from waste incineration, while increasing the proportion of dioxin disposed of in landfills with incinerator ash. The PVC content in the waste steam fed to incinerators has been linked to elevated levels of dioxins in stack air emissions and incinerator ash.

Incineration and open burning of PVC-laden waste seriously impacts public health and the environment. More than 100 municipal waste incinerators in the U.S. burn 500 to 600 million pounds of PVC each year, forming highly toxic dioxins that are released to the air and disposed of on land as ash. The biggest PVC-burning states include Massachusetts, Connecticut,

Maine—which all burn more than half of their waste—Florida, New York, Virginia, Pennsylvania, Maryland, Minnesota, Michigan, New Jersey, Indiana and Washington. The incineration of medical waste, which has the highest PVC content of any waste stream, is finally being replaced across the U.S. by cleaner non-burn technologies after years of community activism and leadership by environmentally-minded hospitals. Backyard burning of PVC-containing household trash is not regulated at the federal level and is poorly regulated by the states. There are no restrictions on backyard burning in Michigan and Pennsylvania. It is partially restricted in 30 states, and banned in 18 states.

PVC Products + Landfill Disposal = Groundwater Contamination

Land disposal of PVC is also problematic. Dumping PVC in landfills poses significant long-term environmental threats due to leaching of toxic additives into groundwater, dioxin-forming landfill fires, and the release of toxic emissions in landfill gases. Land disposal is the final fate of between 2 billion and 4 billion pounds of PVC that are discarded every year at some 1,800 municipal waste landfills in the U.S. Most PVC in construction and demolition debris ends up in landfills, many of which are unlined and cannot capture any contaminants that leak out. An average of 8,400 landfill fires are reported every year in the U.S., contributing further to PVC waste combustion and dioxin pollution.

PVC Products + Recycling = Contamination of the Entire Plastics Recycling Process

Unfortunately, PVC recycling is not the answer. The amount of PVC products that are recycled is negligible, with estimates ranging from only 0.1% to 3%. PVC is very difficult to recycle because of the many different formulations used to make PVC products. Its composition varies because of the many additives used to make PVC products. When these different formulations of PVC are mixed together, they cannot readily be separated which is necessary to recycle the PVC into its original formulation. It's also virtually impossible to create a formulation that can be used for a specific application. PVC can never be truly recycled into the same quality material—it usually ends up being made into lower quality products with less stringent requirements such as park benches or speed bumps.

When PVC products are mixed in with the recycling of non-chlorinated plastics, such as in the "all-bottle" recycling programs favored by the plastics industry, they contaminate the entire recycling process. Although

other types of non-chlorine plastics make up more than 95% of all plastic bottles, introducing only one PVC bottle into the recycling process can contaminate 100,000 bottles, rendering the entire stock unusable for making new bottles or products of similar quality. PVC also increases the toxic impacts of other discarded products such as computers, automobiles and corrugated cardboard during the recycling process.

Safer alternatives are available to replace PVC

Safer alternatives to PVC are widely available and effective for almost all major uses in building materials, medical products, packaging, office supplies, toys and consumer goods. PVC is the most environmentally harmful plastic. Many other plastic resins can substitute more safely for PVC when natural materials are not available.

PVC alternatives are affordable and already competitive in the market place. In many cases, the alternatives are only slightly more costly than PVC, and in some cases the costs of the alternative materials are comparable to PVC when measured over the useful life of the product. Phasing out PVC in favor of safer alternatives is economically achievable. A PVC phase-out will likely require the same total employment as PVC production. The current jobs associated with U.S. PVC production (an estimated 9,000 in VCM and PVC resin production, and 126,000 in PVC fabrication) would simply be translated into production of the same products from safer plastic resins.

How can we get rid of PVC?

To end the myriad of problems created by PVC disposal, we recommend the following policies and activities.

o Policymakers at the local, state and federal level should enact and implement laws that steadily reduce the impacts of PVC disposal and lead to a complete phase-out of PVC use and waste incineration within ten years (see box below).

o A new materials policy for PVC that embraces aggressive source reduction of PVC should be adopted to steadily reduce the use of PVC over time.

o Federal and state waste management priorities should be changed to make incineration of PVC waste the least preferable option.

o In the interim, any PVC waste generated should be diverted away from incineration to hazardous waste landfills.

o Consumers should take personal action to buy PVC-free alternatives and to remove PVC from their trash for management as household hazardous waste.

o Communities should continue to organize against PVC-related dioxin sources such as waste incinerators while working to promote safer alternatives.

A PVC-Free Policy Action Agenda

▷ **Accomplish Within Three Years** ◀

1. Ban all open waste burning.
2. Educate the public about PVC hazards.
3. Ban the incineration of PVC waste.
4. Collect PVC products separately from other waste.
5. In the interim, divert PVC away from incineration to hazardous waste landfills.

▷ **Accomplish Within Five Years** ◀

6. Establish our Right-to-Know about PVC.
7. Label all PVC products with warnings.
8. Give preference to PVC-free purchasing.
9. Ban PVC use in bottles and disposable packaging.
10. Ban sale of PVC with lead or cadmium.

▷ **Accomplish Within Seven Years** ◀

11. Phase out other disposable PVC uses.
12. Phase out other high hazard PVC uses.
13. If safer alternatives are not yet available, extend the PVC phase-out deadlines for specific purposes.
14. Fund efforts to reduce the amount of PVC generated through fees on the PVC content of products.

▷ **Accomplish Within Ten Years** ◀

15. Phase out remaining durable PVC uses.
16. Decommission municipal waste incinerators in favor of zero waste.

INTRODUCTION

PVC—The Poison Plastic

Polyvinyl chloride, commonly referred to as "PVC" or "vinyl," is the second largest commodity plastic in production in the world today. An estimated 59 billion pounds were produced worldwide in 2002 (CEH 2003). Over 14 billion pounds are produced annually in the U.S. (VI 2004). PVC is used in a wide range of products including pipes and tubing, construction materials, packaging, electrical wiring and thousands of consumer goods (Ackerman 2003). The diverse and widespread use of PVC plastic in disposable and durable goods leads to the many immediate and long-term disposal challenges reviewed in this report.

Figure 1 provides a general breakdown of the many uses of PVC. Because of its low cost and aggressive marketing, PVC is found in hundreds of consumer products that are used everyday, including children's toys, credit cards, clothing, carpeting, furniture, flooring, automotive seats, garden hoses, cellular phones, computer parts, office supplies, siding on our homes, roofing and other building materials. A

partial listing of common household products made of PVC can be found in Appendix A.

Plastic pipes and construction uses account for 75% of all PVC consumption in North America. Construction is also the fastest growing PVC sector, with a projected annual average growth rate of 3.5% between 2002 and 2007. Within the construction sector, the fastest growing PVC products are special applications, such as gutters, fencing and decking (growing at 8.1% per year), windows and doors (6.1%), vinyl siding (4.5%) and pipes and tubing (2.5%). PVC use in electrical equipment and electronics is increasing at 2.5% per year. Disposable PVC packaging and transportation-related

Figure 1. Uses of PVC in U.S. and Canada (2002)

Pipes, 45.0%

Consumer Goods, 8.5%

Packaging, 5.8%

Other 5.4%

Electrical/electronic 5.5%

Construction, 29.8%
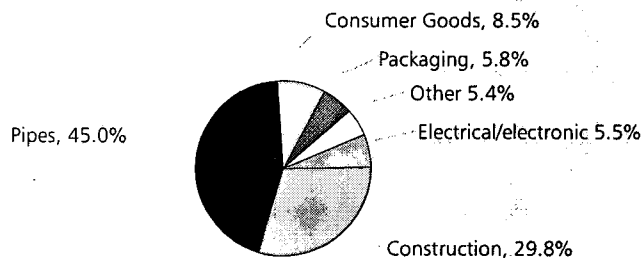
Source: Ackerman 2003, CEH 2003

PVC uses will grow by 2.0% every year over the same five-year period (CEH 2003).

This report reviews the many hazards associated with the disposal of PVC in the United States. Although the report relies primarily on U.S. data on PVC production, use and disposal, the information on the environmental health impacts of PVC are applicable to every country. This report is not intended to be a comprehensive review of all the health and environmental risks posed during the lifecycle of PVC throughout its production, use, and disposal. The key impacts of PVC production and use are summarized in order to provide context for assessing the impacts of the disposal of PVC waste.

Throughout the text we have included a number of case studies that illustrate the impact that PVC has on people. In addition, there are a number of sidebars that highlight actions that some organizations have taken to address the public health or environmental impacts of PVC. The following is a brief summary of the report's findings listed by chapter.

Chapter 2, The PVC Generation: Large and Growing Amounts of PVC Waste,

provides an overview of the amount of PVC waste generated in the U.S. each year and estimates how much ends up in different waste streams. This chapter also addresses how PVC increases the toxicity of these waste streams.

Chapter 3, Trouble From The Start: The Production and Use of PVC,

reviews the production and processing of PVC, which involves chlorine and an array of additives that have serious consequences for public health and the environment during PVC use and disposal. The toxic hazards of PVC additives, including phthalates, heavy metals and flame retardants, are described in this chapter.

Chapter 4, The Deadly Connection: PVC, Chlorine and Dioxin,

reviews the relationship between PVC, chlorine and dioxin, which is especially troubling. Dioxin, one of the most toxic chemicals ever tested, is generated when any form of burning is used as a disposal option for PVC.

Chapter 5, Don't Burn It: The Hazards of Burning PVC Waste,

provides a detailed description of the specific hazards of PVC incineration. Open burning of PVC waste in backyard burn barrels or waste piles is especially troubling because of the large amount of dioxins generated.

Chapter 6, No Place Left: Problems with PVC in Landfills,

reviews the specific toxic hazards associated with the land disposal of PVC. Many PVC additives, including phthalates, heavy metals such as lead and cadmium and organotins, slowly leach out of PVC over time when placed in a landfill, eventually contaminating groundwater and surface water. PVC also worsens the impacts of landfill fires and landfill gases that are generated as materials in the landfill decay.

Chapter 7, Recycling Menace: PVC Undermines Recycling Efforts,

reviews efforts to recycle PVC and details its impacts on plastic recycling programs due to its incompatibility with other commonly recyclable plastics. PVC is extremely hard to recycle because of the numerous additives that are used to make a wide range of PVC products. The toxic by-products of PVC also significantly undermine the recycling of other products.

Chapter 8, Don't Buy It: Safer Alternatives to PVC are Available, Effective and Affordable,

looks at the widespread availability of safer alternatives to PVC and provides a summary of an economic analysis conducted by the Global Development and Environment Institute at Tufts University in Medford, MA. This analysis found that cost-competitive alternatives do exist for most uses of PVC. This chapter includes information on resources that can be used to identify alternatives to PVC.

Chapter 9, Take Action: Preventing Harm from PVC Use and Disposal,

describes actions that can be taken by individuals, local grassroots community-based organizations, statewide organizations, and as part of national efforts to prevent harm from the use and disposal of PVC.

TROUBLE FROM THE START
The Production and Use of PVC

MAJOR FINDINGS

● The production of PVC poses serious environmental health threats due to the manufacture of raw chemicals, including chlorine, cancer-causing vinyl chloride monomer (VCM) and ethylene dichloride (EDC).

● U.S. communities surrounding vinyl chloride chemical facilities, half of which are in Louisiana, suffer from serious toxic chemical pollution of their groundwater supplies, surface waters and air. Residents of the town of Mossville, LA had dioxin levels in their blood that were three times higher than normal.

● PVC includes high amounts of toxic additives, which are released during the use (and disposal) of the product, resulting in elevated human exposures to phthalates, lead, cadmium, tin and other chemicals.

● The use of PVC results in dioxin emissions from PVC combustion which occurs regularly in the U.S due to 1 million annual fires that burn buildings and vehicles—two sectors that consume large amounts of PVC in construction materials.

The Life Cycle of PVC

The 'life cycle' of a product describes the stages that a material goes through from production to disposal. The general life cycle for PVC is shown in Figure 2.

PVC poses environmental and health threats throughout its life cycle, from the production of feedstock chemicals to the final disposal of PVC products. Though some PVC products can pose direct health risks to consumers, most of the hazards associated with PVC occur during production and disposal. An overview of the hazards associated with PVC production, use, and disposal is shown in Table 4.

The major reason why PVC poses so many environmental and health threats throughout its life cycle is because it contains large amounts of chlorine (Thornton 2000). Chlorine is a highly reactive substance that readily combines with carbon molecules, the building block of life in people and animals. Carbon is the most important element in living things because it combines with oxygen, nitrogen and hydrogen to produce stable molecules such as DNA, proteins, hormones, sugars, starches and fats that are essential for life. Chlorine reacts readily with carbon, altering the original molecules and their functions (Thornton 2000).
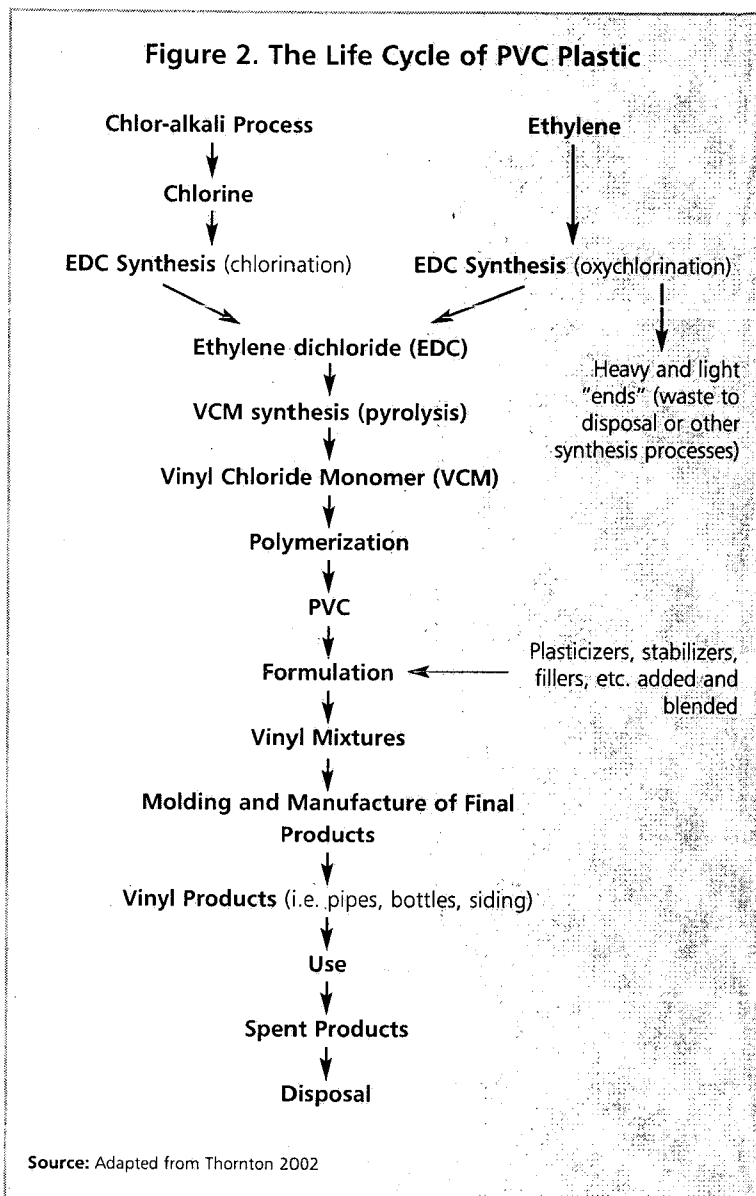
The chlorine in PVC and its feedstocks (ethylene dichloride and vinyl chloride monomer) results in the generation of very large amounts of chlorine-containing

by-products during the manufacture of PVC and the burning of vinyl-containing products and waste. These chemicals include the extraordinarily hazardous chlorinated dioxins and furans, PCBs, hexachlorobenzene, hexachloroethane and hexachlorobutadiene (Papp 1996). Because of the chemical properties of chlorine, these by-products tend to be far more toxic, more persistent in the environment, and more likely to build up in the food supply and the bodies of people than otherwise similar chemicals that do not contain chlorine (Thornton 2000). PVC is the only major plastic that contains chlorine, so it is unique in the hazards it creates.

The chemicals used in the production of PVC (ethylene dichloride and vinyl chloride monomer) are also extremely hazardous. Vinyl chloride is a known human carcinogen that affects the central nervous system and damages the liver (Kielhorn 2000). Ethylene dichloride is a suspected human carcinogen that also affects the central nervous system and damages the liver (USEPA 2003a). Chlorine is a highly irritating gas that damages the upper respiratory system (USEPA 2003b). Hydrogen chloride is a corrosive gas that also affects the upper respiratory system (NAS 2004). These substances pose considerable threats to human health and the environment as a result of PVC production and processing.

Figure 2. The Life Cycle of PVC Plastic

Source: Adapted from Thornton 2002

PVC Production

PVC production begins with the conversion of salt to chlorine using huge amounts of electricity and the purification of ethylene from natural gas (See Figure 2). Chlorine and ethylene are then combined in a chemical reaction to form ethylene dichloride (EDC) in a process generally described as "feedstock production." EDC (considered a "feedstock" chemical) is converted in another chemical reaction to vinyl chloride monomer (VCM), the basic building block of PVC. Vinyl prod-

ucts are then produced in three additional steps. First, polymerization converts the single vinyl chloride monomer into a long chain of vinyl chloride molecules, the PVC polymer or resin. Second, through compounding (or formulation), additives are mixed in with the PVC resin to produce a vinyl formula with desired characteristics such as plasticity, color or resistance to degradation. The ability to change the properties of PVC (making it hard or making it soft or flexible) is what makes it possible to produce a wide range of PVC products. Third, during fabrication (or molding) the product is melted and then molded into its final shape such as a pipe, floor tile or window casing. A more

◦ ◦ ◦ ◦ Table 4 ◦ ◦ ◦ ◦
Overview of Hazards Associated with PVC Production, Use and Disposal

Production

● Dioxin and mercury emissions and asbestos waste from chlorine production.

● Air emissions and wastewater releases from Ethylene Dichloride/Vinyl Chloride Monomer (VCM) production facilities.

● Dioxins and other organochlorines released as by-products of Ethylene Dichloride/Vinyl Chloride Monomer (VCM) production.

● Worker exposures to VCM.

● Incineration of production wastes.

Use

● Additives leach and otherwise migrate from PVC products (plasticizers/metal stabilizers).

● Accidental structure and vehicle fires release dioxins.

Disposal

Landfill

● Accidental landfill fires release dioxins.

● Additives, heavy metals and dioxins leach into groundwater.

● Gaseous emissions from additives.

Incineration

● Dioxins form when PVC is burned.

● Hydrochloric acid, toxic metals and dioxins are emitted to air.

● Ash, later stored in landfills, contains high levels of heavy metals and dioxins.

Recycling

● Diversity of additives prevents effective recycling of mixed PVC products and materials resulting in poor quality products (downcycling).

● Low recycling rates (currently <1%).

● Contaminates other plastics during recycling as well as other valuable commodities that are targeted for recycling.

● Does not reduce the overall demand for raw materials to make plastics (virgin resin) and has no effect on the amount of vinyl produced each year.

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detailed description of the production and manufacturing process for PVC can been found in numerous references (Thornton 2002, Thornton 2000).

In 2000, there were 12 facilities in the U.S. that produced VCM (CEH 2000). Seven of these plants also produced PVC. As of 2003, there were 24 facilities operated by 12 companies that produced PVC resin in the U.S. (CEH 2003) and an estimated 2,332 PVC fabricating facilities (ARCC 2003). These PVC production facilities released 811,000 pounds of VCM and

670,000 pounds of EDC into the environment in 2002 (USEPA 2004). In addition, 6.5 million pounds of VCM and 2.5 million pounds of EDC were sent off-site to sewage treatment plants or waste treatment facilities (USEPA 2004). It should be noted that these are self-reported numbers that represent an absolute minimum. The actual releases are likely to be greater.

During production, most vinyl chloride releases are to the air since it is a volatile gas. A smaller amount of vinyl chloride monomer is released into groundwater or

into wastewater discharged to nearby rivers and streams. The wastes and emissions from production facilities are not limited to vinyl chloride. Dioxins are formed during the oxychlorination process, where chlorine is combined with ethylene gas (or ethylene, oxygen and hydrochloric acid) to form ethylene dichloride (EDC), the primary building block of the vinyl chloride monomer (Evers 1989). Dioxins are also formed when production wastes are incinerated. Incinerators, boilers and acid furnaces burn waste from the oxychlorination process (especially relevant are wastes such as "heavy ends" and distillation tars) and are responsible for the greatest proportion of dioxin releases during PVC production (Thornton 2002). Using data provided by the Vinyl Institute, the USEPA estimates that PVC-only production facilities were a documented source of dioxin air emissions (see Table 6) (USEPA 2001).

Mercury is used in the oldest and most energy intensive process for producing chlorine (Thornton 2002). There are nine chlor-alkali facilities in the U.S. that still use mercury in their process, a 50-year-old technology (Steingraber 2004). Most of this mercury is reused at the plant, but there are still significant air emissions, waste water releases and waste sludge generated (Thornton 2000). Only about 10% of chlorine production in the U.S. still uses mercury, though very little of the mercury-produced chlorine goes to the production of ethylene dichloride or vinyl chloride monomer. The chlorine industry is the largest consumer of mercury in the country (Thornton 2000).

Mercury emissions at these plants are another environmental and public health concern (Steingraber 2004, USEPA 2003c) as mercury causes reproductive and neurological damage (NAS 2000). Mercury is a potent neurotoxin that accumulates primarily as methyl mercury, in aquatic food chains. The highest levels are found in large predatory fish, such as tuna and swordfish. Air emissions of mercury are transported through the atmosphere and eventually settle on land or surface water where natural bacterial processes transform some of the mercury into methyl mercury. Ingestion of mercury-contaminated fish is the primary route of exposure to methyl mercury. Neurodevelopmental toxicity can result from the exposure of pregnant women and young children to mercury, leading to learning disabilities in children (USEPA 2003c, NAS 2000).

Plants that manufacture ethylene dichloride and vinyl chloride monomer are a risk to workers and residents of surrounding areas. In the early 1970's, plants that manufactured vinyl chloride were found to be exposing workers to levels of the chemical high enough to put

them at risk of developing a rare form of liver cancer—angiosarcoma. In 1974, the industry finally admitted that workers exposed to vinyl chloride did develop this rare form of liver cancer (Creech 1974). Residents of communities near vinyl chloride production plants are also affected by plant emissions. These plants discharge pollutants into nearby communities, contaminating drinking water and releasing dioxins into the air from on-site incinerators. Besides cancer, workers and residents alike are vulnerable to a range of ailments associated with vinyl chloride exposure, including damage to the liver, lungs, blood, nervous system, immune system, cardiovascular system, skin, bones and reproductive system (Kielhorn 2000, ATSDR 1997). More detailed analyses of the human health and environmental impact of PVC production processes can be found in numerous references (Steingraber 2004, USEPA 2002, Kielhorn 2000, ATSDR 1997).

Although the levels of vinyl chloride and ethylene dichloride released from these facilities are lower today than in the past, exposure to these substances is still a concern. There appears to be no safe level of exposure for these substances, especially vinyl chloride. Both of these substances are considered to be "genotoxic" meaning that they cause irreversible damage to DNA (Kielhorn 2000). A generally accepted scientific theory is that mutation in a single cell can result in cancer (Pitot 1991). Similarly, exposure to a genotoxic substance can lead to DNA damage. This means there is no safe level of exposure to these substances and any exposure increases the risk of developing cancer, a birth defect or a genetic disorder. Thus, lower emissions from vinyl chloride and ethylene dichloride facilities reduce, but do not eliminate, health and environmental risks.

The production and disposal of PVC poses dangers relevant to everyone, but often, particular groups of people are especially at risk. Plants that manufacture the ethylene dichloride and vinyl chloride monomer are often located in low-income areas or communities of color, as are incinerators that burn PVC waste and landfills that store PVC waste (Thornton 1997). These types of sites pose a threat. Community-based groups understand the threat these facilities pose to their communities. The urgency of their opposition to these facilities speaks to the intensity of the danger that they feel these facilities pose.

CASE STUDY

Mossville, Louisiana:
PVC Production in the New "Cancer Alley"

In Calcasieu Parish, Louisiana, residents of Mossville, a small unincorporated community of about 1,500 African Americans, are confronting numerous toxic industries including four vinyl production facilities that include two major vinyl chloride manufacturers. Louisiana is home to more than half of the 12 vinyl chloride plants in the U.S., and Calcasieu Parish produces more vinyl than any other county in the country making it the unofficial PVC capitol of America. At the urging of Mossville residents, air monitoring conducted by the U.S. Environmental Protection Agency (USEPA) in June 1999 showed vinyl manufacturing facilities emitted concentrations of vinyl chloride, a potent human carcinogen, that were more than 120 times higher than the ambient air standard—making the air in Mossville unhealthy to breathe. PPG Industries and Condea Vista in Mossville leaked hundreds of thousands of pounds of ethylene dichloride, a feedstock for PVC, and contaminated the groundwater. As a result of this contamination and a lawsuit settlement with two companies, a significant portion of Mossville families have relocated. This has transformed a once highly populated neighborhood into a virtual ghost town. The Condea Vista facility has changed ownership, but has not improved. The portion of the facility now owned by Sasol Ltd. continues to be ranked in the top 10% of industrial companies that create the highest cancer risk from air and water pollution according to the USEPA 2002 Toxic Release Inventory. This data shows that in 2002 vinyl production facilities in Mossville generated 238,458,615 pounds of toxic waste that were dumped on the community or transferred to disposal facilities. Over 30 million pounds of this waste wound up in landfills and incinerators located in other communities.

In 1998, Mossville Environmental Action Now, Inc. (MEAN) appealed to the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) to test residents for exposure to dioxin, a highly toxic compound that is a by-product of vinyl manufacturing and other industrial processes. In 1999, ATSDR reported dioxin test results showed the average Mossville resident has three times more dioxin in their blood than the average U.S. citizen. Furthermore, testing of breast milk from local mothers found elevated levels of dioxins as high as 30% above the national average. Cancer mortality rates for Calcasieu Parish are 1.6 times the national average and many women suffer from endometriosis, a condition linked to dioxin exposure.

The citizens of Mossville are determined in their search for justice. As descendants of African Americans who proudly settled the community in the late 1800's, they have inherited not only the land, but also the fighting spirit to survive and demand what is rightfully theirs. Working through MEAN, they have lobbied successfully for government action. Through use of a Bucket Brigade program, which allows residents to test their own air, they have caused industry to be fined as much as $300,000 when testing showed benzene levels 231 times greater than the state standard. In 2001, Sasol Ltd., a South African company with chemical and fuel operations in 20 countries, acquired Condea Vista. Working in solidarity with communities in South Africa, SasolWatch.com was created to expose the company's record of violations and toxic dumping on poor communities. MEAN is working with a local health care provider to develop necessary environmental health services for Mossville residents. The organization is educating the public about the dangers of PVC production, use and disposal. MEAN is also demanding significant pollution reduction, the clean-up of industrial contamination in the local estuary, and the just and fair relocation of consenting residents to a healthier environment (Sources: MEAN 2000, Ermler 2001, LBB 2004, SasolWatch 2004, Greenpeace 2004a, Greenpeace 2004b).

PVC Use

PVC plastic used in consumer products is not a pure material. By the time a product containing PVC reaches your home, a wide range of chemicals have been added in order to change its properties to meet a wide range of product needs. These additives include stabiliz-

ers, plasticizers and fillers that are mixed in with, but are not chemically bound to the PVC. A list of common additives found in PVC products is shown in Table 5.

The most important of these chemical additives are the plasticizers known as phthalates (pronounced 'thal-eights') and the metal stabilizers. Plasticizers are added

Table 5

Common Additives Found in PVC

Stabilizers

Lead • Cadmium • Antimony • Organotins • Zinc

Plasticizers

Diethylhexylphthalate (DEHP) • Diisononylphthalate (DINP)

Diisodecylphthalate (DIDP)

Source: CEC 2000, DEPA 1995

to PVC to "soften" the plastic and make it pliable for certain applications. About 90% of all phthalates consumed in the U.S. (and about 98% in England) are used in PVC products (Thornton 2002, OECD 2004). These plasticizers can make up a large portion, in some cases up to 60% by weight, of the vinyl product (DTI 1995). Because these additives are not chemically bound to the PVC, they will leach out over time (Thornton 2002).

Studies have shown plasticizers such as diethyl-hexylphthalate (DEHP) and diisononylphthalate (DINP) have migrated out of PVC containers used to store food (CR 1998, DTI 1995); IV bags used to hold blood (Pearson 1993, Tickner 1999); toys (NET 1999, Stringer 1997); and numerous other products, exposing people to these toxic additives (DEPA 2001, Harmon 2001, HCWH 2002).

In some cases, these additives will evaporate or "off-gas" from PVC materials like flooring, wall covering or carpeting, contaminating indoor air (CARB 1999, Rudell 2000, Uhde 2001). A study by the California Air Resources Board measured forty target compounds off-gassing from PVC flooring. Phenol was found in the air off-gassing from all the vinyl sheets evaluated. Tetrahydofuran, cyclohexanone, toluene and n-tride-cane were also found (CARB 1999). Another study found the degradation of plasticizers from PVC flooring was likely responsible for an increase in adult asthma as well as eye and skin symptoms in workers. The prevalence of these symptoms decreased when the PVC flooring was removed (Tuomainen 2003). A Swedish study estimated that 42,000 tons of phthalates are released from PVC products worldwide each year (DTI 1995). The familiar "new car" smell or the odor from a newly opened shower curtain represents the release of phthalates evaporating from a PVC product (Thornton 2000).

Components of PVC have also been found to leach from PVC pipes. Vinyl chloride has been found to leach from PVC pipes made prior to 1977 (Yaw 1999). PVC pipes made prior to this time had a high residue of vinyl chloride that failed to bond when the vinyl chloride monomer was polymerized into polyvinyl chloride. In a study of unplasticized PVC pipe, vinyl chloride was detected in water after 30 days at 2.5 parts per billion (ppb), a level that exceeds the USEPA drinking water standard of 1 ppb (Al-Malack 2000). Smaller pipe size, longer line length, and warm temperatures all increase the likelihood of vinyl chloride leaching from PVC pipes. Additional studies have found organotin stabilizers also leach from PVC pipes (Sadiki 1999, Sadiki 1996, Wu 1989, Forsyth 1997).

Phthalates have been shown to cause developmental and reproductive damage (NTP 2000), altered liver (Woodward 1990) and kidney function (Seth 1982) and have been linked to the development of respiratory problems in children (Jaakkola 1999, Oie 1997). More detailed information on the health and environmental impact of phthalates used in PVC products are available from many resources (ATSDR 1997, HCWH 2002, Rossi 2001).

Metal stabilizers are used in PVC to prevent degradation from heat during processing and from exposure to ultraviolet light during the useful life of a product (Pless 2002). They include lead, cadmium, zinc, antimony and the organotins (see Table 5). These metals will leach out of PVC products. Lead and cadmium were found to leach out of children's toys made with PVC (DiGangi 1997). Lead migrated out of PVC window blinds (CT 1996) and into water carried in PVC pipes (DTI 1995). Lead is a known cause of neurodevelopmental problems (USEPA 2004a). Cadmium causes cancer and kidney damage (USEPA 2003d).

Organotin stabilizers (tributyltin, tetrabutyltin, monooctyltin, dioctyltin) were introduced to replace toxic metal stabilizers like lead and cadmium, but they have also been found to leach from PVC products (Sadiki 1999, Harmon 2001). The organotins are also toxic. They affect the central nervous system, skin, liver, immune system and reproductive system (WHO 1980, Pless 2002). The diorganotins, such as dioctyltin, are potent developmental toxins (Ema 1995, Pless

2002) and potent teratogens (Noda 1993, Pless 2002). Tributyltin affects the nervous system, and has caused reproductive and developmental problems in animal studies (Boyer 1989, ATSDR 1992).

Antimony trioxide (ATO) is added to PVC used in flexible electrical cables and roofing foils (an alternative to roofing felt on flat roofs) to inhibit the formation and spread of flames during a fire (UBA 2001, DEPA 1999). For flame retardant applications, PVC accounted for 32% of the European market for antimony trioxide in 1998 (UBA 2001). The antimony, which is a synergist rather than a flame retardant, acts to enhance the flame retarding properties of chlorine in PVC. Antimony trioxide is a suspect human carcinogen when inhaled and is toxic to the lungs, heart, eyes and skin (UBA 2001, NAS 2000a). During fires and waste incineration, antimony dust and toxic antimony halides are released. Antimony also catalyzes the formation of dioxins and furans (UBA 2001).

Other flame retardants added to PVC include chlorinated paraffins, phosphate esters (organic phosphorus compounds some of which also contain chlorine or bromine) and aluminum trihydroxide (UBA 2001). These additives are used in high volumes but are also used in many other polymer applications in addition to PVC. Chlorinated paraffins and antimony are added as a flame retardant formulation for some PVC textile fibers that are resistant to soaking and weather (UBA 2001). Chlorinated paraffins are complex mixtures of short-chain and long-chain hydrocarbons containing up to 70% chlorine. Chlorinated paraffins cause liver and kidney toxicity in animals while the short-chain mixture is an animal carcinogen and possible human carcinogen (NAS 2000a). Chlorinated paraffins and phosphate esters in PVC also function as secondary plasticizers (UBA 2001).

The phosphate ester flame retardants used in PVC include tris (2-chloroethyl) phosphate, tris (chloropropyl) phosphate [TCCP], and tris (dichloropropyl) phosphate [TDCPP]. These compounds are added to PVC floor covering and are released as off-gassing occurs from the vinyl (Marklund 2003). TDCPP was widely used as a flame retardant in children's sleepwear until May 1977, when it was withdrawn from the market after published reports that it was mutagenic in bacteria (Sanders 1978). The use of TDCPP as a flame retardant may pose significant cancer risks and reproductive harm (testicular atrophy and decreased seminal vesicle secretions), according to a committee of top U.S. scientists (NAS 2000a). The German Federal Environmental Agency has recommended a reduction

in the use of TCCP in favor of safer substitutes, since it has high environmental persistence with some evidence of carcinogenicity. (UBA 2001).

Structural and Vehicle Fires

Another hazard associated with the use of PVC products arises when PVC is burned in an accidental fire. Not only are many building materials made from PVC but it was once standard practice to use PVC to insulate wiring in buildings. In 1995, there were an estimated 574,000 structural fires and another 406,000 vehicle fires in the U.S. (USEPA 2001). When the PVC in buildings and vehicles burns, a variety of toxic substances are formed that pose major public health risks. The primary combustion products are hydrogen chloride gas, carbon dioxide and carbon monoxide (OFM 1997). Hydrogen chloride gas is a corrosive and highly toxic gas that can burn the skin and cause severe damage to the eyes and lungs. When hydrogen chloride comes in contact with the mucous lining of the lungs, it is converted into hydrochloric acid that can cause severe and permanent respiratory damage (IAFF 1995).

Accidental fires that burn PVC also generate phosgene gas, benzene, toluene, xylenes, dioxins, furans and other products of incomplete combustion (IAFF 1995). The poor combustion conditions that are typical of these fires are ideal for the formation of dioxins and furans (TNO 1996). Dioxins were found in the air, water, surface soil and nearby vegetation following the burning of a plastics recycling plant in Hamilton, Ontario (OMEE 1997). In the World Trade Center fires, dioxins and furans were identified as significant components of the smoke given off by the smoldering buildings (Landrigan 2004). In Germany, dioxin levels in indoor soot remaining after a house fire were found to be as high as 45,000 parts per trillion (ppt) TEQ—more than 300 times the German government's health standard (Fiedler 1993). After a fire at a plastics warehouse in Binghamton, NY, dioxin levels in soils were found to be more than 100 times higher than other areas of the community not impacted by the fire (Schecter 1996).

Firefighters and emergency responders are especially at risk from smoke and gases generated by fires burning PVC. Exposure to combustion gases from building fires has been linked to a high incidence of leukemia and laryngeal and colon cancers in firefighters at young ages (Wallace 1990) and to other adverse health problems including pulmonary hemorrhage and edema due to chemical pneumonitis (Schreiber 2003, Dyer 1976). This is one of the reasons why the International

Association of Fire Fighters supports the use of alternative building materials that do not pose as high a risk as PVC (Duffy 1998).

The toxic gases generated when PVC is burned in accidental fires have resulted in deaths and injuries, including workers exposed to toxic gases from burning electrical wires coated with PVC (Colardyn 1978); residents exposed to airborne toxics from a Hamilton, Ontario plastics recycling plant fire (Upshur 2001); and guests who died in the MGM Grand Hotel fire in Las Vegas (Buerk 1982). A summary of the public health hazards associated with accidental fires that burn PVC has been published elsewhere (Schreiber 2003).

PVC's use to insulate wiring has raised concerns not only for its use in buildings, but also in airplanes. The use of PVC insulation around wiring was once standard practice in airplanes. A typical airplane, for example, could contain more than 100 miles of PVC coated wiring (Ackerman 2003). Insulation of the wires is critical to air safety, but defects in the insulation can lead to short circuits and sparks that could potentially start a fire or spark an explosion. If PVC wiring overheats and starts to smolder, large amounts of smoke are generated and, if moisture is present, hydrochloric acid can be produced. Although there is no proof that PVC insulation has ever caused an airplane crash, concerns have been raised about older airplanes that still contain PVC-insulated wires. Use of PVC wiring is now prohibited on new planes since PVC insulation failed Federal Aviation Administration flammability tests (Ackerman 2003).

Accidental fires are unexpected, and thus difficult to regulate, but phasing out PVC could reduce the harm they cause. If PVC was not so widely used as a building material, accidental fires would not produce the toxic combustion products that are specifically caused by the

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C A S E   S T U D Y

Illiopolis, Illinois: PVC Plant Explodes

On April 23, 2004, a PVC plant operated by Formosa Plastics in Illiopolis, Illinois exploded. A towering plume of smoke containing dioxins, hydrochloric acid, vinyl chloride and vinyl acetate could be seen for miles around. The explosion caused both power and water to be cut off and over 900 people were evacuated from the community. People were stationed in makeshift shelters including the local shopping mall. The U.S. Chemical Safety and Hazard Investigation Board called the explosion the most serious the agency has investigated since it was founded in 1998. Four workers were killed instantly and one died shortly after being hospitalized.

Nearly three months after the disaster, the Illinois Environmental Protection Agency (IEPA) reported elevated levels of dioxin were found in the soil at 12 of 13 sites sampled. Some samples reached levels of 50 ppt—10 times higher than normal. Some areas tested were as far as 3 miles from the explosion. Residents are concerned about the constant health risks posed by these hazardous sites. More testing is planned. (Sources: Antonacci 2004, IEPA 2004, Steingraber 2004a).

C A S E   S T U D Y

Montreal, Canada:
PVC Fire and Firefighter Exposure

A 1993 fire in St. Terese, Canada at a plastics plant called Plastibec, Ltd consumed more than 15 tons of PVC. The plant manufactured vinyl blinds and vinyl window frames. After burning for 18 hours and forcing 250 people from their homes, the smoldering structure continued to emit thick black smoke. In the end, the fire produced between 40-85 grams of dioxins and furans, equal to the amount released by the pulp and paper industry in an entire year. Of the 50 firefighters called out to the blaze, 6 were treated for smoke inhalation and more than 30 required medical treatment after being exposed to the fumes (Source: Greenpeace 1994).

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burning of PVC. Both immediate and long-term impacts would be lessened: firefighters and victims alike would avoid exposure to the toxic gases and smoke caused by the fire, and the leftover ash would be largely free of these toxins as well.

THE DEADLY CONNECTION
PVC, Chlorine and Dioxin

MAJOR FINDINGS

- When burned, PVC plastic, which contains 57% chlorine when pure, forms dioxins, a highly toxic group of chemicals that build up in the food chain.

- The PVC content in the waste stream fed to incinerators has been linked to elevated levels of dioxins in stack air emissions and incinerator ash.

- PVC is the major contributor of chlorine to four combustion sources— municipal solid waste incinerators, backyard burn barrels, medical waste incinerators and secondary copper smelters—that account for a significant portion of dioxin air emissions. In the most recent USEPA Inventory of Sources of Dioxin in the United States, these four sources accounted for more than 80% of dioxin emissions to air (based on 1995 data).

The Formation of Dioxin

A major concern about PVC is the formation of dioxin during production and during disposal through incineration. The term 'dioxin' refers to a family of chemical compounds that are not intentionally made. They are generated as by-products during production and disposal of chlorinated compounds including PVC. There are many forms ("congeners") of dioxin, each with a different toxicity. The most toxic form is 2,3,7,8-tetra-chlorodibenzo-p-dioxin (TCDD), and is the standard against which the toxicity of all other forms of dioxin is measured. TCDD is a known human carcinogen according to the U.S. National Toxicology Program (USHHS 2002), World Health Organization (WHO 1997) and U.S. Environmental Protection Agency (USEPA) (USEPA 2000). Dioxin is fat-soluble, which means it will bioaccumulate in increasing concentrations as it moves up the food chain. Exposure to dioxins is associated with reproductive and developmental health problems, and has been shown to impair immune system response and interfere with normal hormone function (Birnbaum 2003).

The PVC-Dioxin Connection

The relationship between PVC and the formation of dioxins in incinerators is clear: PVC is a significant chlorine donor in the incineration process, spurring the formation of dioxins. The strongest evidence of this

comes from laboratory studies. The German EPA found that burning waste that includes PVC or other organochlorines produced dioxins, while burning waste without PVC did not (Theisen 1991). Two Danish studies found similar results (Vikelsoe 2000, Christmann 1989). In Japan, researchers found that adding 4% PVC to a mixture of PVC-free material increased dioxin emissions ten fold (Ishibashi 2000). When PVC was added to a mixture of newspapers or to chlorine-free paper and burned, dioxin emissions increased significantly with chlorine and PVC content (Yasuhara 2001). In a similar study, dioxin levels in fly ash were 200 to 1,200 times higher when PVC was added to a mixture of newspaper or chlorine-free plastics (Takasuga 2000). Several other studies found increased dioxin levels in fly ash or unburned residue were correlated with increased PVC levels in the waste stream burned (Kopponen 1992, Kolenda 1994, Wunderli 2000).

When elemental chlorine was added to a mixture of coal and salt, dioxin levels were 130 times higher than when the same mixture was burned without the chlorine (Mahle 1980). Adding PVC or chlorine gas to chloride-containing vegetable matter resulted in increased dioxin formation (Liberti 1983). In another study, as the level of organochlorines in a waste stream increased, so too did the amount of dioxins formed (Altwicker 1993). A study in Finland found that burning perchloroethylene in a laboratory produced more dioxins, chlorobenzenes and chlorophenols than burning sodium chloride (Halonen 1995).

There is also evidence from small-scale incinerators that support a relationship between burning organochlorine compounds like PVC and dioxin formation. The Danish EPA found that doubling the PVC content of an incinerator's waste feed increases dioxin emissions by 32% (DEPA 1995). Conversely, reducing the PVC feed results in a reduction in dioxin emissions. Researchers in Japan found that burning a mixture of PVC and polyethylene produced large amounts of dioxins (Tamade 2000, Yoneda 2000). A study conducted for the Dutch Environment Ministry found that PVC levels in the waste stream increased dioxin levels in the air emissions (Kanters 1996). Other studies in both the U.S. (Wagner 1993) and Europe (Christmann 1989, Vesterinen 1996, Halonen 1993, Hutari 1996, Manninen 1996, Hatanaka 2000) have found a positive correlation between PVC content in a waste stream and dioxin emissions.

An excellent review of the evidence linking chlorine content in the waste stream and dioxin emissions has

been published (Costner 2001). This paper identified 47 studies involving laboratory and pilot scale combustion system/processes; 12 studies involving small-scale and other combustion systems/processes; and 31 studies involving full-scale combustors that are relevant to the relationship of chlorine content and dioxin emissions. The author found that reduced chlorine content was correlated with reduced dioxin formation in all three study groups and concluded that there is "a compelling body of evidence that dioxin formation in waste incinerators decreases when chlorine input is reduced."

The USEPA confirmed that PVC is a dioxin precursor in 1997 (USEPA 1997). They also acknowledged that, "several studies have identified strong correlations between chlorine content and CDD/CDF [dioxin/furan] emissions during combustion tests." As part of the Inventory of Sources of Dioxin developed by the USEPA, the agency acknowledged that a "review of experimental data clearly indicates an association between chlorine content of feed/fuels and ... synthesis of CDDs and CDFs" (USEPA 2001). However, the agency concluded that the results on whether a relationship between chlorine input and dioxin emissions exists were not "unequivocal" and left it at that.

Additional insight into the relationship between PVC and dioxin emissions can be found by examining the USEPA Inventory of Sources of Dioxin. Table 6 summarizes dioxin emissions from sources that include PVC. The table shows facilities that burn PVC are responsible for most of the dioxin sources identified. Eight quantified air sources and eight non-quantified air sources are identified that include PVC as a chlorine contributor in the waste stream. There are also quantified releases to water and land from sources that clearly contain PVC as a chlorine donor. In addition, quantified sources such as tire burning and asphalt mixing plants may contain PVC when household garbage is burned with tires, or when PVC is added as "filler" in producing asphalt. In fact, any process that burns household garbage—including gasification or pyrolysis (systems that burn waste in the absence of oxygen) — can be expected to generate dioxin emissions in large part due to the presence of PVC in the waste (BREDL 2002). The table also shows a number of other unquantified sources that may include PVC as a contributor to dioxin emissions. The data used to generate these estimates were collected in 1995 and represent the most recent data available on dioxin emissions in the U.S. (USEPA 2001).

The top four quantified sources alone—municipal solid waste incinerators, backyard barrel burning, medical

● ● ● Table 6 ● ● ● ●

Dioxin Emissions in the U.S. from Sources that Include PVC

Sources with Chlorine from PVC	Dioxin Releases (grams/year TEQ*)
Quantified Air Sources	
Municipal solid waste incinerators	1,250 [see note below]
Backyard barrel burning	628
Medical waste incinerators	488
Secondary copper smelters	271
Cement kilns burning hazardous waste	156
Cement kilns not burning hazardous waste	17.8
EDC/VCM production	11.2
Hazardous waste incineration	5.8
Non-Quantified Air Sources	
Landfill fires	
Landfill gas	
Accidental fires	
Scrap electrical wire recovery	
Secondary ferrous metal smelting	
Ferrous foundries	
Manufacturing chlorine and chlorine derivatives	
PVC manufacturing	
Other Possible Air Sources	
Sewage sludge	14.8
Asphalt mixing plants	7
Secondary lead smelters	1.72
Tire burning	0.11
Total Dioxin Releases to Air	**3,125**
Quantified Releases to Water	
Ethylene dichloride/vinyl chloride	0.43
Quantified Releases to Land	
Ethylene dichloride/vinyl chloride	0.73
Municipal waste water sludge	76.6

Sources and Notes: All data are from the USEPA Inventory of Sources of Dioxin (USEPA 2001) which reflects data generated in 1995, the most recent year for which data are available. Since the 2001 Inventory was published, dioxin air emissions from municipal waste incinerators have declined for two reasons related to a December 2000 compliance deadline for new federal regulations on toxic air emissions: (1) the closure of 25 waste combustion plants, nearly 20% of the total number, between 2000 and 2002 (Kaufman 2004); and (2) added air pollution controls that shifted much of the total amount of dioxin formed to incinerator ash, which requires land disposal. The USEPA now estimates that dioxin air emissions from large municipal waste incinerators are 12.0 grams of dioxin per year (TEQ) from 66 large incineration facilities in 24 states (USEPA 2002a). Dioxin air emissions from 39 small incinerators were estimated at 50 grams per year TEQ in 2000 and are projected to decline to 1.8 grams per year in response to a December 2005 compliance deadline for new federal toxic air emission regulations (ERG 2002). These more recent estimates have not yet been peer reviewed or published according to USEPA.

* TEQ = toxic equivalents; a measure of the total amount of all forms of dioxins, furans, and dioxin-like PCBs found in a sample.

waste incinerators and secondary copper smelters—account for 2,637 grams TEQ, which is equivalent to 84% of the annual total estimated dioxin emissions to air. Clearly, not all of these emissions are attributable to PVC. Dioxin can be generated when other chlorine donors are present. The fraction attributable to PVC is not known.

It is clear from this evidence that without PVC, there would be considerably less chlorine in the incinerator feed and hence less dioxins formed. This is not to say that chlorine content is the only factor determining dioxin production. It is not. Facility design, operating conditions and the presence of catalysts also matter, but numerous studies support the conclusion that without chlorine, dioxin cannot be formed and that PVC is the predominant source of chlorine in the waste stream (Costner 2001).

It is misleading to focus only on stack air emissions when assessing chlorine's contribution to dioxin formation. Fly ash, bottom ash and other residues contain dioxin as well. Two studies on municipal waste incinerators provide evidence that only from 0.0004 to 1% of total dioxins formed remain in the stack gases (Fabrellas 1999, Sakai 1997). Other research has shown that there is a positive correlation between dioxin concentrations in ash and the amount of PVC in the waste feed. In one study, when PVC was burned with wood, dioxin levels increased in the ash (Wilken 1994). In another study, higher dioxin concentrations were observed in ash residue from chlorinated plastics than in ash from chlorine-free paper, wood, cotton or wool (Theisen 1991). In general, as more PVC is added, dioxin levels rise.

Nonetheless, most studies focus on dioxin concentrations in stack gas as a means of assessing the relationship between chlorine and dioxin. The fact that many studies examining miniscule dioxin concentrations in this hard-to-measure source still find a positive correlation between chlorine and dioxin testifies to the strength of the relationship.

Despite this compelling body of evidence, the Chlorine Chemistry Council (CCC) has aggressively argued that there is no relationship between PVC content and dioxin emissions from incinerators. The industry's prime support for this claim is a study funded by the Vinyl Institute, a member of the CCC, conducted by an industry consultant and published by the American Society of Mechanical Engineers (ASME). This study examined data from 169 facilities and concluded that there was "little or no correlation between chlorine input and dioxin emissions from incinerators" (Rigo 1995). This study has been critiqued and its methodology shown to be invalid (Thornton 2002, Costner 2000, Costner 1997, Chien 2003). In addition, the conclusions of the ASME study were refuted at a workshop held by the USEPA in 1996 on Dioxin Formation Processes and Sources (Costner 2000).

Furthermore, a memo prepared prior to the release of the ASME study by the public relations firm Nichols-Desenhall Communications (under contract to the

Vinyl Institute) calls into question the derivation and perhaps the integrity of the ASME study. This memo laid out a strategy to diffuse any connection between chlorine content/PVC and dioxin emissions made by the USEPA as part of their Dioxin Reassessment effort. The memo recommends the Vinyl Institute fund an "independent" scientific study to "debunk" the USEPA's claim about the positive relationship between PVC and dioxin emissions (Burnett 1994). This study turned out to be the one conducted under contract with the consulting firm of Rigo & Rigo Associates under the auspices of ASME. An internal Vinyl Institute memo described the role of the ASME, "The purpose of the ASME as the contractor is to provide unassailable objectivity to the study ..." (Goodman 1994). In this same memo, Rigo was described as "... willing to set his priorities to our needs, and he appears sympathetic to Plastics, Vinyl, PVC and Cl2 ..." Additional details on these memos have been described elsewhere (Thornton 2002).

PVC is the primary source of chlorine in the waste stream. Eliminating PVC would dramatically reduce the amount of chlorine being burned, and thereby limit dioxin formation. Given the abundant evidence implicating chlorine as an essential precursor to dioxin formation, it is important to reduce if not eliminate the levels of PVC in the waste stream. Banning PVC would be the most effective means of achieving this goal.

DON'T BURN IT
The Hazards of
Burning PVC Waste

MAJOR FINDINGS

⊚ More than 100 municipal waste incinerators in the U.S. burn 500 to 600 million pounds of PVC each year, forming highly toxic dioxins and releasing toxic additives to the air and in ash disposed of on land.

○ The largest PVC-burning states include Massachusetts, Connecticut, Maine—which all burn more than half of their waste—Florida, New York, Virginia, Pennsylvania, Maryland, Minnesota, Michigan, New Jersey, Indiana and Washington.

○ The incineration of medical waste, which has the highest PVC content of any waste stream, is being steadily replaced by cleaner non-burn technologies.

⊚ Open burning of solid waste, which contains PVC, is a major source of dioxin air emissions and dioxin-laden ash, as well as other dangerous pollutants.

⊚ Backyard burning of PVC-containing household trash is not regulated at the federal level and is poorly regulated by the states—it is completely unrestricted in Michigan and Pennsylvania, partially restricted in 30 states and banned in 18.

When PVC is burned in municipal and medical waste incinerators, dioxins and other toxic gases are formed and heavy metals present in the waste are released into the air and residual ash. Dioxins are also released when residents in rural areas dispose of their trash by burning it in small furnaces or barrels behind their homes, and when PVC products or waste are burned in building, vehicle and landfill fires.

Municipal Waste Incinerators

Incineration, or high-temperature burning, is frequently used to dispose of municipal, hazardous and medical wastes. Because PVC is a widely used plastic (especially in medical applications), the waste burned in these incinerators inevitably contains PVC. As discussed earlier, the chlorine in PVC facilitates the formation of dioxins and other chlorinated organic compounds that are subsequently released to the environment (Costner 2001). Thus, incinerators are a major source of dioxins released to the air and land, and PVC is largely responsible for this situation.

Municipal waste or household trash incinerators are considered the largest source of dioxin emissions in air (USEPA 2001). The most recent inventory of dioxin sources in the U.S. estimated municipal and medical waste incinerators together account for 55% of all dioxin releases to air (40% and 15%, respectively) (USEPA 2001). Dioxin air emissions have since declined as

● ● ● Table 7 ● ● ●

States with the Heaviest Reliance on Municipal Waste Incineration

State	Percent Incinerated (After Recycling)	Number of Incinerators	Amount of PVC Incinerated (tons)
Maine	66.2%	4	5,448
Connecticut	55.4%	6	16,257
Massachusetts	54.6%	7	28,145
Minnesota	46.1%	15	14,432
Florida	37.1%	13	45,364
Hawaii	32.7%	1	3,454
Virginia	27.9%	5	18,806
New York	24.4%	10	37,517
Maryland	22.6%	3	12,486
Pennsylvania	22.6%	6	17,746
New Hampshire	22.2%	2	1,675
Remaining States*	Varies	32	49,075
Total	10.5%	104	250,405

Sources and Notes: Estimates derived from Kaufman (2004) for 2002. The amount of PVC incinerated by each state was calculated by: (1) assuming that the percent PVC content of municipal solid waste (0.62%) estimated by the USEPA (2003) is representative of the typical percentage of PVC in the waste stream; (2) assuming that post-consumer recycling of PVC in MSW is zero; (3) multiplying the average percent PVC in the waste (0.62%) by the total waste generated in that state according to Table 4 in Kaufman (2004); and (4) multiplying this value (the total PVC disposed in the state) by the percent of waste incinerated after recycling as shown in column 2 above. The percent of PVC incinerated after recycling was determined by dividing the total amount of waste incinerated in a state (provided in Table 4 of Kaufman 2004) by the total waste disposed of (after recycling).

* 19 states did not burn any MSW according to Kaufman 2004 and AL, AK, and MT did not report any data (see Appendix B).

incinerators have closed or added pollution controls to meet new standards (USEPA 2002a, ERG 2002). Now much of the dioxins formed from incinerators are released to the land through landfilling of incinerator ash.

Table 7 lists those states that rely heavily on incineration as a disposal option for municipal solid waste. Maine, Connecticut, and Massachusetts incinerate more than 50% of their municipal solid waste destined for disposal (not counting the amount of waste recycled). Minnesota has the largest number of municipal waste incinerators (15) followed by Florida (13) and New York (10). These states have been dependent on waste incineration since the late 1980's and early 1990's. This trend may have been motivated by zealous protection of abundant groundwater and surface water supplies; limited potential for new landfill capacity; subsidies for generating electricity from waste burning; and state policies which favor incineration over land disposal. A complete listing of the amount of

As shown in Table 7, an estimated 250,000 tons (500 million pounds) of PVC is burned in trash incinerators in the U.S. each year (Kaufman 2004). This estimate is even higher if you use the municipal solid waste data generated by the USEPA. Using the USEPA data for the year 2001, the amount of PVC burned is estimated to be about 600 million pounds (USEPA 2003). These values are consistent with other estimates (Thornton 2002). As discussed earlier, PVC waste contributes substantially to the chlorine content of the waste and to the formation of dioxins in trash incinerator emissions. Estimates of how much PVC waste contributes to the chlorine content in waste streams vary from 35 to 66% (CEC 2000, ECC 1994). Other minor chlorine sources include food waste and paper. Another source estimates that, on average, about 50 to 67% of the chlorine input in an incinerator can be attributed to PVC (Thornton 2002). However, as much as 80% of the organically bound chlorine, which is thought to be more conducive to dioxin formation than inorganic chlorine, is from PVC (Thornton 2000).

In addition to dioxins, PVC waste contributes to the formation of hydrochloric acid (HCl) in the flue gases of incinerators. This gas must be neutralized (primarily by lime) and removed by scrubbers. HCl damages the air pollution control equipment because it is so corrosive and requires additional maintenance. In addition, the metal stabilizers in PVC (lead and cadmium) do not break down during incineration but are released either as hazardous air emissions or remain in the ash and cinders (ECC 1994). Older PVC products that used cadmium as a metal stabilizer will contribute cadmium when burned (ECC 1994). Consequently, the more PVC in the waste stream the greater the operating cost of the incinerator due to: (1) the use of more agents to neutralize the acids and flue gases; (2) additional operating and repair costs; and (3) additional waste management costs to dispose of the residual ash (CEC 2000).

Waste incineration has been linked to a number of serious health problems in plant workers, as well as in surrounding communities. Many of these troubles implicate PVC as the root source of contamination. For instance, workers in incinerator plants have increased levels of chlorinated phenols and lead in their body tissues, which may result from PVC, as well as mercury and arsenic (Allsopp 2001). The USEPA has reported that metals emissions in incinerators rise when the chlorine content of the waste rises. In one study, metals were up to seven times higher when the chlorine content of the waste was increased from 0 to 8.3% (Carroll 1989). Elevated chlorine content levels also impair the efficiency of the scrubber (an air pollution control device) to remove metals from stack gases (Carroll 1989). Incinerator operators are not the only exposed group. Populations living near incinerators are particularly vulnerable to elevated levels of dioxins and heavy metals in tissue and blood, as well as to respiratory ailments and cancers (Allsopp 2001). Elevated levels of congenital abnormalities have also been observed in newborns in areas in the immediate vicinity of incineration plants (ten Tusscher 2000).

Even distant populations are at risk, as toxic air releases settle on crops and these crops are transported to other areas and/or eaten by livestock which, in turn, are consumed by people (Cohen 1998, Cohen 1995). A study by Barry Commoner and researchers at Queens College in New York found Inuit Native peoples living in the northern reaches of Canada, miles from any sources of dioxin, had high levels of dioxin in their bodies (Commoner 2000). These researchers also found dioxins released from incinerators and other dioxin sources hundreds of miles away in the U.S. and lower Canada were transported by wind currents to the far reaches of the globe.

A common argument in favor of incinerators is that they significantly reduce the weight and volume of waste going to landfills. While waste volume is reduced by about 45 to 50%, this statement only tells part of the story. The fly ash captured by the air pollution control equipment and the residual ash left in the burner must be disposed of in landfills and is often more toxic than the original raw waste. This is the result of burning metal-containing materials (including PVC), chlorine-containing PVC waste that generates dioxins, and other difficult to burn waste. This ash is stored in landfills, and often leaches into surrounding soil and water. Incineration may indeed reduce the volume of waste going to landfills, but in doing so, this practice shifts the waste burden to air releases and increases the toxicity of the waste that will eventually be landfilled in the

form of ash. Incineration is not a solution to waste disposal, especially not for PVC-containing waste.

Medical Waste Incinerators

Incineration of medical waste involves the burning of solid waste generated primarily by hospitals and research facilities. PVC accounts for 5 to 15% of medical waste (DTI 1995, Hasselriis 1993, Marrack 1988, USOTA 1988). Medical products made of, or containing, PVC include surgical gloves, dialysis tubing, blister packs, inhalation masks, IV bags/tubing, mattress covers and blood bags. Even non-medical products containing PVC (e.g., office supplies) are often burned along with medical trash.

As the overall volume of waste generated by hospitals has increased over the past 50 years, so has the proportion of that waste containing PVC. In 1996, PVC accounted for 27% of all plastic used in durable and disposable medical products (Rossi 2000). This growth in the use and disposal of vinyl medical products has led to increased chlorine input to medical waste incinerators and thus greater dioxin formation. In 2001, the USEPA cited medical waste incinerators as the 3rd largest source of dioxin releases to the environment in the U.S (USEPA 2001).

In 1990, roughly 70% of U.S. hospitals used on-site incinerators (USOTA 1990). According to the USEPA, the number of medical waste incinerators operating in the U.S. dropped roughly in half from 1987 to 1995 (USEPA 2001). Similarly, the amount of medical waste burned in these incinerators dropped from an estimated 1.43 billion kilograms (kg) in 1987 to 0.77 billion kg in 1995. Today there are substantially fewer medical waste incinerators operating (USEPA 2004b). Some of this drop is due to new regulations that have gone into effect, which increased operating costs (USEPA 2000a). But the work of activist grassroots citizen organizations and national groups like Health Care Without Harm have played a major role in shutting down medical waste incinerators and encouraging the use of non-incineration treatment technologies (HCWH 2001, Lester 2003).

Hospital waste primarily consists of general solid waste (70%), medical waste (17%), patient waste (9%) and a small amount of hazardous waste (2%). Approximately 15% of this waste is considered to be infectious waste (HCWH 2001), which requires treatment to disinfect the waste but not necessarily incineration. Viable alternatives to incineration exist for the disposal of the

remaining 98% of medical waste that is non-pathological. Much of this waste is paper, cardboard, plastic, metals and general solid waste that does not need to be burned.

The most prominent alternative for treating hospital waste is autoclaving—a process that disinfects the biological waste component. Other treatment methods include microwaving, electro-thermal deactivation, gasification, chemical disinfection and thermal treatment (HCWH 2001). Yet even these alternatives do not address the underlying problem, the initial use and generation of PVC wastes. A better solution is to replace PVC products with non-chlorinated plastics.

Given the finding in recent studies that flexible PVC products used in hospitals (like dialysis tubing) leach toxic additives into patients' bodies (USFDA 2001, NTP 2000), the imperative to employ alternatives is stronger than ever. Additives mixed in with PVC to make it flexible or rigid are not chemically bound to the plastic and are thus prone to leach from the material. One such additive, a phthalate called 2-diethylhexyl phthalate (DEHP), has been found to leach from soft plastic, and has been documented to have a significant impact on the development of the male reproductive system and the production of normal sperm in young animals (Moore 2001). Also linked with DEHP exposure is respiratory distress, changes in kidney and liver function, ovarian dysfunction and decreased hormone production in females (Rossi 2001).

Open Burning

Perhaps the most under appreciated source of dioxin emissions is the open burning of household trash.

CASE STUDY

Detroit, Michigan:
Henry Ford Hospital Medical Waste Incinerator

In February 2000, residents of a predominately African-American community in Detroit, Michigan succeeded in their efforts to shut down Henry Ford Hospital's medical waste incinerator. Since it began operating in 1980, the facility had been burning approximately 6 million pounds of waste annually. As of 1998, Henry Ford was the only hospital (of 25 surveyed) still burning medical waste in an on-site incinerator. Environmental justice was a primary concern: the Henry Ford Hospital System owns two other hospitals located in predominately white suburbs that send their waste to a commercial autoclave facility in Toledo, Ohio rather than burn it. This inconsistency fueled local activists.

The Henry Ford Hospital incinerator was a major, chronic polluter. For instance, the only emission controls in place were opacity limits, which do not involve emissions testing, but use a visual estimate of how 'opaque' a cloud of smoke emitted from the stack is. And even those limits had been violated on a number of occasions. Federal pollution controls on emissions of mercury, dioxins and heavy metals had not yet been implemented in Michigan, so the facility burned medical and other waste largely without regulation. The impact on public health was consequently severe. A five year long Michigan Department of Community Health study found the rate of children hospitalized for asthma in the zip codes immediately surrounding the incinerator to be three times that of neighboring Wayne County. Moreover, a report commissioned by the New York University Research Program focusing on Ambulatory Care Sensitive Conditions in Michigan from 1983 through 1994 found that in the four zip codes surrounding the incinerator, the average hospital admissions of children aged zero to four were four times the state average.

A coalition of more than a dozen organizations including Detroiters Working for Environmental Justice, Virginia Park Citizen's District Council, a local Sierra Club chapter, and the Sugar Law Center for Economic and Social Justice worked together for four years before successfully closing the incinerator in the spring of 2000. Strategies included civil disobedience, media attention and coalition building. Yard signs helped draw attention to the fight, and a constant barrage of phone calls and postcards to hospital officials ensured residents' concerns would not be ignored. Steady, targeted pressure on executives within Henry Ford Hospital System was a major factor in the eventual shutdown of the incinerator (Sources: Lott 2004, Holden 1999, Bates-Rudd 2000).

CASE STUDY

Oakland, California:

IES Medical Waste Incinerator

On December 10, 2001, after a 4-year struggle, Integrated Environmental Systems (IES) was forced to shut down its commercial medical waste incinerator in Oakland, California. Even under "perfect" operating conditions, the incinerator was known to emit dioxins, mercury and other toxic pollutants. The facility was also notorious for all kinds of permit violations including excess emissions, broken monitors, odors, uncontrolled bypasses of the pollution control devices and worker safety violations.

The Coalition for Healthy Communities and Environmental Justice, consisting of Oakland residents and community, health, and environmental justice organizations, formed to bring an end to the IES incinerator. After having ignored emissions and permit violations for years, the Bay Area Air Quality Management District finally took action by declining to renew the facility's operating permit in 2001. When IES insisted on its intentions to keep burning millions of pounds of medical and non-medical waste every year, a powerful direct action was planned and executed by the Coalition. Community protesters blocked the entrance to the IES incinerator for eight hours nonviolently putting their bodies in front of trucks carrying waste.

Owing largely to the community's powerful voices and actions, IES sold its company to competitor Stericycle in December 2001 who is reportedly planning to tear down the incinerators and close the facility (Sources: Greenaction 2001, Greenaction 2001a).

CASE STUDY

Gila River Indian Reservation, Arizona:

Stericycle Medical Waste Incinerator

Members of the Gila River Indian community near Chandler, Arizona organized as the Gila River Alliance for a Clean Environment and succeeded in forcing Stericycle to shut down a medical waste incinerator operating on tribal land in 2002. The incinerator had been burning medical and non-medical waste from several states for about 10 years, and was among the largest in the U.S. Waste from hospitals, medical and dental offices, mortuaries and research institutes was among the waste being burned. When Stericycle's lease for the facility came up for renegotiation, activists seized the opportunity to push for cleaner technologies like autoclaving. The renegotiated lease will allow only an autoclave on the site. With the closure of this facility, there are now no commercial medical waste incinerators in Arizona, Nevada, or California (Source: Greenaction 2002).

Open burning, also called uncontrolled burning or backyard burning, involves the burning of household trash by residents on their property. Burning typically occurs in a burn barrel, open fireplace or furnace, homemade burn box, wood stove, outdoor boiler or open pit (USEPA 2003e). Most backyard burning occurs in rural areas where there is no curbside trash pickup. According to government surveys, an estimated 20 million people in rural areas burn trash in their backyards (MDEQ 2003).

The smoke and vapors from the open burning of household trash contain many toxic chemicals that can affect people's health and the environment, including dioxins and furans; carbon monoxide; heavy metals such as mercury, lead, arsenic, and cyanide; volatile organic compounds (VOCs) such as benzene, styrene, and formaldehyde; particulates; polycyclic aromatic hydrocarbons (PAHs); and hexachlorobenzene (USEPA 2003f, MDEQ 2003). Exposure to these chemicals have been linked to adverse health problems including, but not limited to asthma, lung cancer, and other respiratory ailments, kidney and liver damage, and nervous system, reproductive and developmental disorders (USEPA 2003g). One study found emissions were highest for VOCs such as benzene and styrene, formaldehyde, hydrogen cyanide and hydrochloric acid, followed by polychlorinated biphenyls (PCBs) and arsenic (MDEQ 2003).

Among the toxic byproducts of backyard waste burning, dioxins and furans may pose the greatest public health threat. Dioxins are highly toxic even at low levels and have been linked to serious health problems in people that include cancer and adverse developmental and reproductive effects (USEPA

2003g, Birnbaum 2003). Dioxins are formed primarily because of low combustion temperatures, poor air distribution, and the presence of chlorine (USEPA 2003h). The majority of chlorine in household trash comes from PVC plastic. Because the emissions from open burning are released close to the ground, they are particularly dangerous to people and animals located nearby. There are also no pollution control devices on these burners.

The backyard burning of household trash also produces residual ash that contains toxic metals such as lead, chromium, mercury and arsenic, as well as PCBs and dioxins (USEPA 2003f, Lemieux 1998). The ash left over from the burning is often used by homeowners in gardens or placed in areas where children may play and come in contact with these toxic substances. In gardens, vegetables can absorb and accumulate the metals (USEPA 2003f).

Open burning was not initially identified by the USEPA as a source of dioxin (USEPA 1998). Now the agency has identified open burning as a major source of dioxins. The USEPA's most recent Inventory of Sources of Dioxin estimated open burning may account for as much as 628 grams TEQ dioxin, making it the second largest source of dioxin emissions in the U.S. (USEPA 2001). The USEPA found a single household burn barrel may release more toxic chemicals into the air than a municipal waste incinerator burning 200 tons of household trash a day that is equipped with state-of-the-art air pollution control devices (Lemieux 1998).

A key study used by the USEPA to estimate the amount of dioxins generated by open burning of household trash was published in 1998 by a New York researcher (Lemieux 1998). The author burned two sets of simulated household garbage in separate metal burn barrels in a controlled laboratory setting and measured emissions from each barrel. One barrel contained simulated waste from a household that did not recycle and the other contained waste remaining after "avid recycling." This study reported high emissions of volatile organic compounds (VOCs) including benzene, polynuclear aromatic hydrocarbons (PAHs), chlorinated benzenes and dioxins and furans. Surprisingly, higher levels of dioxins and furans were found in the emissions from the avid recycling household sample compared to the non-recycler.

CASE STUDY

Maine Bans Backyard Burning; Warns Public About PVC Hazards

Reducing dioxin emissions and protecting the health of Maine residents was a high priority when the Maine legislature voted to prohibit backyard trash burning in 2001. This new law and PVC educational outreach followed a citizen advocacy campaign led by the Natural Resources Council of Maine which focused on reducing the use and disposal of PVC because of its role as a dioxin-forming consumer product. A 1997 study found 10,000 backyard burn barrels across rural Maine and documented the high levels of dioxin emissions and exposures that resulted. The law also required the Maine Department of Environmental Protection (DEP) to educate people about dioxin-forming PVC products and their alternatives.

An educational bulletin, poster and flyer prepared and distributed by the Maine DEP contain clear and compelling messages about PVC.

> "We can make a difference by RETHINKING our purchasing habits to avoid putting PVC products in the waste stream."

> "You can help to reduce dioxin pollution from municipal trash incineration by: REPLACING #3 PVC Products with 'less polluting' natural materials OR safer plastic alternatives #1 PETE, #2 HDPE, #4 LDPE, #5 PP."

> "PVC plastics waste is a major source of our dioxin pollution in Maine. It is the only plastic that forms significant amounts of dioxin when burned and has very low recycling rates. It is even preferable to avoid burning PVC in municipal incinerators to reduce air pollutant levels and toxic ash disposal. Safe alternatives exist for virtually every use of PVC plastic."

Maine's educational materials also give clear consumer guidance on safer alternatives to typical uses of PVC plastic. The Maine DEP established the link between open burning and PVC as follows: "In addition to eliminating backyard trash burning, we need to reduce the toxic nature of our waste stream that goes to incineration because of the potential for serious health effects and contamination of our food supply" (Sources: MDEP 2001, MDEP 2001a, MDEP 1997).

A likely explanation for this difference may be the higher proportion of PVC plastic which is not recycled that ends up in the trash of the avid recycling household (4.5% versus 0.2%). According to the author of the study, "the higher proportion of PVC plastic in the avid recycler's waste stream could potentially increase the formation of chlorinated organic compounds." Other factors such as time, temperature history, mixing patterns, oxygen availability, as well as the mixture of carbon with chlorine in the presence of metal catalysts are also important factors in the formation of PCDDs (dioxins) and PCDFs (furans) (Lemieux, 2000).

Initially, USEPA considered that PVC content in the waste might be a key determinant of dioxin emissions during open burning (Lemieix 1997, Gullett 1999). They conducted several experiments to evaluate the effect of PVC and chlorine input on dioxin emissions (Gullett 1999, Gullett 2000, Gullett 2001). The latest study concluded that the chlorine in the waste does appear to influence dioxin emissions, but only at high levels not typically found in household trash, and dioxin emissions were independent of the source of chlorine (Lemieux 2003).

A recent reanalysis of this same data found a very strong correlation between PVC and dioxin emissions in the USEPA burn barrel experiments (Neurath 2004). This study found that the percent chlorine, especially the percent PVC, were "the most important predictors of dioxin emissions"—not combustion variables such as carbon monoxide, temperature, or air input levels as claimed by the USEPA (Neurath 2004). Backyard burning is not like an incinerator where you can control these variables. By definition, uncontrolled burning is uncontrolled. What can be controlled is the type of waste, such as PVC, that is burned.

Open burning of household trash is thought to account for a considerable share of dioxin air emissions in many states including Maine (26%) (MDEP 2004) and New Hampshire (17%) (NHDES 2001). Some states including Massachusetts, Maine, Vermont, Connecticut, North Carolina, New Mexico, and Washington (USEPA 2003i), recognize the threat to public health and have adopted regulations completely banning open burning of household trash. Others, such as Alaska (AKDEC 2004) and California (CARB 2003), while allowing the burning of paper, cardboard and yard waste, have specifically banned the burning of plastic, rubber and other hazardous materials.

Figure 3 includes data originally developed by the New Hampshire Department of Environmental Services and updated in 2004. The figure shows open or backyard burning is illegal in 18 states, restricted in 29 states, completely unrestricted in two states (Michigan and Pennsylvania) and left to local government in one state

Figure 3. Current State Regulations on Backyard Burning of Household Waste in the U.S.

Illegal (18)
Legal (2)
Legal with Restrictions (29)
Regulated by Local Gvt. (1)
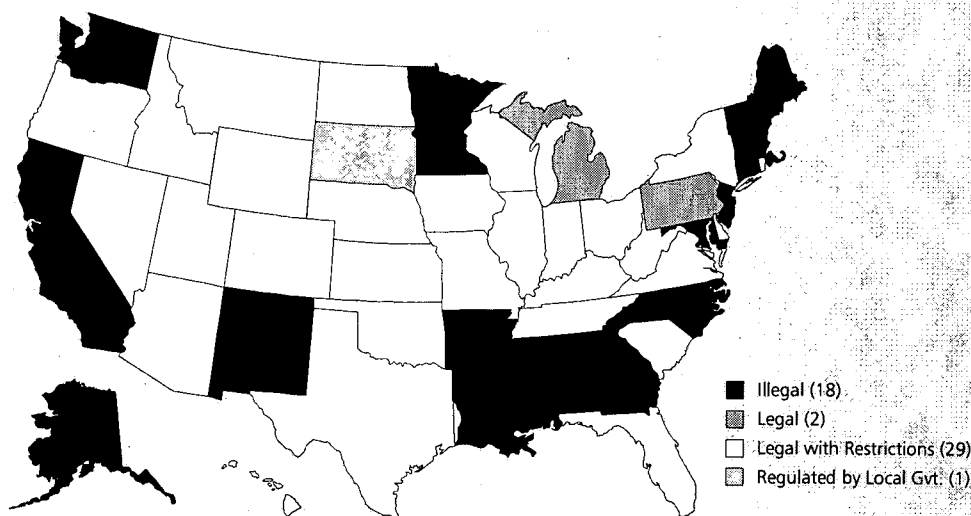
Source: Adapted from NHDES 2001

(South Dakota) (NHDES 2001, NHDES, 2003, NMED 2004, CARB, 2003a, MRSA 2004). Several states that have yet to enact proper legislation (e.g., Rhode Island, New York, Pennsylvania) have issued public health statements and developed pamphlets warning of the dangers associated with burning plastic, specifically the release of dioxins. The USEPA currently has no regulations that apply to open burning even though they estimate that it is one of the largest sources of dioxin in air (USEPA 2001). To assist in finding current regulations for each state, the USEPA has constructed a virtual map on their Website with links to each state's rules and regulations (USEPA 2003i).

Regulations on open burning typically vary between rural and urban/suburban areas. While generally prohibited in highly populated areas and municipalities, open burning is seldom stringently regulated in rural areas. One reason given for this has been that decisions on whether to restrict or ban open burning of household trash has been driven by citizen complaints (Lighthall 1998). Thus, those communities with enough people to generate a substantial number of complaints are the ones that enact or adopt policies to restrict or ban the open burning of household trash.

Every state has distinct laws though, and even within states, rules are far from uniform. Even in those states and areas where rules and regulations exist, enforcement is extremely difficult. This lack of coherence tends to stifle efforts to curb open burning in general and PVC burning in particular. Unless open burning can be curtailed or even adequately controlled, it is unrealistic to expect PVC will not be burned. PVC will continue to harm human and environmental health as long as open burning continues to be used to dispose of trash.

In addition to open burning of household trash, vehicle fires, structure fires, construction site burning and landfill fires all represent significant types of uncontrolled PVC combustion. Because PVC is so ubiquitous, the chance that it will be burned in intentional or accidental fires is high.

The cost of waste disposal has risen in recent years, and many rural residents are unable or unwilling to pay these increased costs. Otherwise laudable "pay-as-you-throw" (variable rate pricing) programs in communities across the nation aim to reduce waste, but in rural areas accustomed to paying a fixed rate regardless of the amount of waste they generate, such programs actually tend to trigger an increase in burning and illegal dumping. Rather than reduce the amount of waste generated, the more appealing option for some is illegal dumping and/or open burning. Moreover, proper disposal is often less convenient in rural areas. Burning trash may be a more appealing option than driving long distances to pay for and legally dispose of trash. State and local governments must address matters of affordability and convenience in these areas in order to help bring an end to open burning (MEDEP 1997). In the long term though, replacing PVC with safer alternatives is the only way to eliminate PVC from the waste stream.

NO PLACE LEFT
Problems with PVC
in Landfills

MAJOR FINDINGS

● Dumping of PVC in landfills poses significant long-term environmental threats due to leaching of toxic additives into groundwater, dioxin-forming landfill fires and toxic emissions in landfill gases.

● Land disposal is the final fate of between 2 billion and 4 billion pounds of PVC that is discarded every year in some 1,800 municipal waste landfills.

● Many of the more than 1,900 landfills used for disposal of construction and demolition (C&D) debris are unlined and can not capture any contaminants that leak out of PVC building material waste.

● An average of 8,400 landfill fires are reported every year in the U.S., contributing further to PVC waste combustion and dioxin pollution.

Landfilling is the most common disposal option for PVC and thus is a significant part of the disposal stage of the PVC life cycle. The majority of PVC that is discarded as waste ends up in a landfill. However, landfills do not solve the PVC disposal dilemma. They eventually leak, routinely emit toxic gases and occasionally catch on fire. Landfills merely represent a temporary, polluting alternative to burning PVC and creating dioxins. As an interim strategy, land disposal of PVC is preferable to incineration, but it does not provide a long-term secure solution to PVC waste management.

Municipal Waste Landfills

In 2001, about 79% of U.S. municipal solid waste destined for disposal was landfilled (USEPA 2003). According to data made available by the USEPA, about 1.42 million tons of PVC was in U.S. municipal solid waste in 2001 (USEPA 2003). This represents less than one percent of the 163 million tons of municipal solid waste disposed of in landfills and incinerators. (This total does not include an additional 49 millions tons of municipal discards that were recycled or composted and contained negligible amounts of PVC).

The USEPA data establishes a low-end estimate of about 1.12 million tons of PVC (more than 2.2 billion pounds) that was dumped in landfills in 2001 (USEPA 2003). Using another source of data on municipal waste generation for 2002, the amount of PVC dumped

in landfills was estimated at 2.04 million tons, or more than 4 billion pounds (Kaufman 2004), nearly twice the USEPA amount. This latter estimate assumes the same percent PVC content in the municipal solid waste stream as reported by the USEPA.

The estimated number of active landfills in the U.S. that accept PVC for disposal in municipal solid waste varies. Citing 2002 data reported by 47 states, Kaufman lists a total of 1,767 municipal solid waste landfills (Kaufman 2004). USEPA concluded that 1,858 landfills received municipal solid waste in 2001 (USEPA 2004c). Yet another source estimates that there are 3,200 municipal solid waste landfills (EREF 2004).

Table 8 lists those states that rely heavily on landfilling as a disposal option for municipal solid waste in the U.S. California, Texas and Michigan landfill the most waste. Texas has the largest number of landfills (175), followed by California (161) and Florida (100). A total of 19 states including Texas, Ohio, and Illinois landfill 100% of their waste. A complete listing of the amount of PVC landfilled in each state is show in Appendix B.

The amount of PVC waste going to landfills is expected to increase substantially over the next 20 years. A study in Europe found the amount of PVC waste generated in the 15 European Union countries will increase from 3.6 million tons per year in 2000 to 4.7 million tons in 2010 and to 6.4 million tons per year by 2020 (AEA 2000, ARGUS 2000). This is an increase of more than 75% over 20 years. This is because most PVC products were put into commercial use during the 1970's and their useful service life is ending. Components in cars, construction materials, and electrical, household and industrial goods typically last from 5 to 15 years (AEA 2000). Building materials such as pipes, flooring, and siding may last for decades before being replaced (AEA 2000). As production of these

○ ○ ● **Table 8** ● ○ ○

Estimated Amounts of PVC Discarded in Landfills According to States that Landfill the Most Municipal Solid Waste (MSW)

State	Number of Landfills	Amount of PVC Landfilled (tons)
California	161	328,260
Texas	175	176,896
New York	26	116,088
Ohio	44	100,509
Illinois	51	98,896
Michigan	52	96,241
Florida	100	76,817
Georgia	60	69,177
Pennsylvania	49	60,844
New Jersey	60	56,166
North Carolina	41	54,842
Indiana	35	52,986
Washington	21	49,128
Virginia	67	48,636
Maryland	20	42,722
Remaining States*	805	610,553
Total	**1,767**	**2,038,761**

Sources and Notes: Estimates derived from Kaufman (2004) for 2002. The amount of PVC landfilled by each state was calculated by (1) assuming that the percent PVC content of municipal solid waste (0.62%) estimated by the USEPA (2003) is representative of the typical percentage of PVC in the waste stream; (2) assuming that post-consumer recycling of PVC in MSW is zero; (3) multiplying the average percent PVC in the waste (0.62%) by the total waste generated in that state according to Table 4 in Kaufman (2004); and (4) multiplying this value (the total PVC disposed in the state) by the percent of waste landfilled after recycling as shown in column 2 above. The percent of PVC landfilled after recycling was determined by dividing the total amount of waste landfilled in a state (provided in Table 4 of Kaufman 2004) by the total waste disposed of (after recycling).

* AL, AK, and MT did not report any data (see Appendix B).

PVC materials has been on going for more than 30 years, the PVC waste that is entering the waste stream today is a reflection of the products put in use years ago. An estimated 300 billion pounds of this PVC will require disposal worldwide in the coming years (van der Naald 1998).

Construction and Demolition Waste Landfills

PVC is also found in construction and demolition (C&D) waste. C&D waste is generated from the construction, renovation, repair and demolition of structures such as residential and commercial buildings, roads, and bridges (ICF 1995). Franklin Associates

(under contract to the USEPA) estimated that 136 million tons of building-related C&D debris was generated in 1996 (FA 1998). This figure did not include road, bridge and land clearing debris. C&D waste consists mainly of wood products, asphalt, drywall and masonry waste with lesser quantities of metals, plastics including PVC, dirt, shingles, insulation, paper and cardboard (ICF 1995). The percentage of PVC in C&D waste is hard to estimate. One report specifically identified and estimated the percent of vinyl siding and PVC pipes in C&D waste to be 0.63% for the two materials combined (FA 1998). Other types of PVC plastic waste were not considered.

In 2002, forty-two states reported that 1,931 landfills were dedicated for disposal of C&D waste (Kaufman 2004). Many if not most of these landfills are unlined, offering groundwater supplies even less protection from contaminants that may leach from PVC and other C&D waste components.

The Hazards of Landfill Disposal of PVC

There are significant dangers associated with the dumping of PVC in landfills. Although there appears to be little degradation of the PVC polymer (ARGUS 2000, Mersiowski 1999), the additives present in PVC products are not chemically bound to the PVC and they will seep out into the environment over time (CEC 2000). These additives include plasticizers, stabilizers, pigments, fillers and other chemicals that are added to PVC depending on the final product's intended purpose (see Chapter 3). Many of these additives leach out in the disposal phase (Mersiowski 1999). This is especially true of flexible PVC products. In the case of the rigid PVC products, stabilizers are generally thought to be encapsulated in the matrix of the PVC polymer and thus migration is expected to be less than what occurs with the plasticizers (ARGUS 2000, AEA 2000, Mersiowski 1999).

In landfills, PVC (as well as all waste) is subject to different reactive conditions such as moisture, changing temperatures, the presence (or absence) of oxygen, and the activity of microorganisms (CEC 2000). These factors will interact with the waste at different stages of the aging process. Recent studies evaluating the behavior of PVC in landfills found that microorganisms and/or corrosive liquids common to landfill environments act to accelerate the release of additives in PVC products (Mersiowski 1999, Hjertberg 1995).

Cadmium, lead, organotins and phthalates (which account for over 90% of plasticizers) are commonly released from PVC waste in landfills (Mersiowski 1999, Hjertberg 1995). In studies evaluating the leaching of bisphenol A (BPA), an additive used in many plastics, PVC was found to release the highest concentrations of BPA (Yamamoto 1999). These additives will mix with water and other substances in the waste and generate "leachate" which will contaminate local groundwater in the vicinity of the landfill.

Leachate generated by waste in landfills has been detected in groundwater monitoring wells at numerous garbage landfills (Lee 1996). One study in California reported that 72% of 528 landfills had polluted the nearby groundwater (Lee 1996). The USEPA passed regulations in 1991 to control landfill leachate (USEPA 1991). These regulations have been criticized for relying on a "fundamentally flawed technological approach for MSW management that at best only postpones when significant environmental problems will occur as a result of the landfilled waste" (Lee 2003).

Estimates have been made of the amount of lead present in landfills that are attributable to lead additives in discarded PVC products. These estimates range from 1 to 28% (CEC 2000). In 1998, an estimated 51,000 tons of lead were used as stabilizers in plastic in Europe (CEC 2000) and an estimated 6 billion tons were used worldwide in 2000 (Tukker 2001). Much of this lead will end up in landfills and can be expected to be a significant source of lead being released into the environment (NCM 2003). The key question is how much of the lead will be mobilized and released into the environment and when. Although the mobility of lead is generally thought to be low, small amounts will slowly leak out. Over time, this could lead to substantial amounts of lead being released into the environment. One study in Europe reported that an estimated 8 kilotons of lead from PVC entered the waste stream and that 0.5 kilotons was released into the environment in 2000 (Tukker 2001). Given the longevity of PVC products, it can be expected that lead leaching from discarded PVC products in landfills will continue to be a health and environmental threat for many years to come.

The lack of adequate liners and/or leachate treatment in many old landfills (and even some new ones) ensures that these releases have an easy route into surrounding groundwater and soil. Many construction and demolition debris landfills are completely unlined. Most old landfills contain no liner or collection system to prevent leachate generated in the landfill from mixing with and

contaminating local groundwater. This leachate will seep down through the waste and eventually contaminate groundwater with hazardous and toxic chemicals (Lee 1994).

Even landfills equipped with the best liners and most up-to-date treatment methods cannot ensure long-term safety. In instances where liners or collection systems have been installed, leachate is still generated. When it reaches the bottom of the landfill, it is collected by a system of pipes and treated. The treated leachate is often sprayed back onto the waste and eventually collected again. If these pipes clog up, the leachate will accumulate in the landfill and create pressure on the liner. Eventually, this pressure will force the leachate out at the point of least resistance, usually the bottom of the landfill when the bottom liner fails.

These collection systems can be clogged by silt or mud, the growth of microorganisms in the pipes, or chemical reactions leading to the precipitation of minerals in the pipes. The pipes may also become weakened by chemical attack (acids, solvents, oxidizing agents or corrosion) and may be crushed by the tons of garbage piled on them (ERF 1989)

The liners used in landfills are generally made from high-density polyethylene (HDPE). These liners can be degraded by a number of household chemicals that can cause them to either lose strength, soften or become brittle and crack. Liners will also tear during installation or as a result of pressure from the weight of the waste. There may also be defects in the liners such as cracks, holes and faulty seams that allow leachate to pass through the liner (ERF 1992). One study found certain organic chemicals, such as chlorinated solvents, benzene, trichloroethylene (TCE) and vinyl chloride, can readily pass through an intact liner (i.e., a liner with no holes) in a short period of time (Haxo 1988). This finding has been confirmed in separate studies (Sakti 1991, Buss 1995, Lee 1996). Eventually, all landfills will leak whether they have a liner or not (ERF 1992, Bonaparte 1990, Lee 1992) and threaten the health of residents living nearby (ERF 1998). Landfills cannot guarantee safe, long-term disposal of PVC wastes and their by-products.

Landfill fires present another cause for concern. These fires generate a range of hazardous gases including carbon dioxide, carbon monoxide and hydrogen chloride. Dioxins and furan are also formed (USEPA 2001). Such fires are not uncommon. An average of 8,400 landfill fires are reported each year in the U.S. (FEMA 2002) and their ignition can be traced to a number of

causes. Though over half of reported fires have no information available as to the initial cause, 40% of reported fires are classified as deliberate or suspicious, 20% are attributable to smoldering waste, and 5% ignite spontaneously. Highly flammable methane gas, released by landfilled waste as it decays is a primary factor in many cases.

PVC products disposed of in landfills contribute to the formation of dioxins and furans in the event of a fire. Four PVC products—pipes, rigid foils, floorings and cable wires—contribute about 40% of the chlorine content in landfills (Mersiowsky 1999). As previously discussed, the chlorine in PVC contributes to the formation of dioxins. Other factors that influence the amount of chlorinated dioxins and furans formed include fire temperature, and the availability of oxygen and catalysts (e.g., copper). Lower oxygen concentrations and lower temperatures (500-700° C) correspond with elevated dioxin formation (Moeller 1996). Both these conditions occur frequently at landfill fires.

Measured concentrations of dioxins and furans in the air of landfill fires are generally high and consistent with evidence gathered from test fires (Ruokojärvi 1995). As is the case with open burning, these air emissions are unfiltered and largely uncontrolled (see Chapter 3).

Another concern with landfills is the generation of landfill gases. All municipal waste landfills generate gases that result from the degradation of materials in the waste (USEPA 1995). The most common landfill gas is methane that results from the degradation of biological matter in the waste stream. Other common landfill gases include vinyl chloride, benzene, toluene and dichloroethane (ATSDR 2001). These volatile gases result from the breakdown of waste components present in the landfill. When PVC degrades, plasticizers and other additives leach out, and some of these evaporate and contribute to the landfill gases (ARGUS 2000).

Older landfills made no attempt to vent or control these gases. As a result, there were many explosions in homes and buildings located near solid waste landfills caused by the migration of methane gas, a highly explosive substance (USEPA 1990, Lee 1994). More modern landfills attempt to capture these gases using a gas collection system. These systems consist of a series of wells installed throughout the landfill that are used to pull out the gas. A series of pipes connect the wells and carry the gas to either a flare where it is burned or to an energy recovery system where the gases are con-

verted into electricity (USEPA 1990). The flares can be a source of dioxins if chlorinated chemicals such as vinyl chloride are present in the landfill gases (USEPA 2001, Eden 1993).

Since 1996, large landfills have been required to have gas collection systems, which, the USEPA maintains, capture 75% of the gases (USEPA 2002b). However, there is no factual basis for this number. There are no studies that define the collection efficiency of these systems. Instead, this estimate is intended to reflect the best achievable efficiency while the systems are operating. The flaws in EPA's estimate are two fold. First, more of the gases are emitted both before the systems are installed and after they are removed from service, than during the time they are functional. Second, most landfills do not achieve best practices, especially because there is no way to measure emissions that might disclose poor efficiency, other than by detecting odor problems, which is just the manifestation of the worst fugitive emissions. A study that includes these factors found that there is no factual basis to conclude that, in practice and on a lifetime basis, more than 20% of the landfill gases generated are actually captured and either flared or used to recover energy (Anderson 2004a).

Landfills are also used to discard the residual ash generated when PVC products are incinerated. This ash contains dioxins and many heavy metals that will eventually cause many of the same leaching problems and threats to groundwater discussed earlier (USEPA 1994a, ERF 1990, Denison 1988). Clearly, landfills do not solve the disposal dilemma. They merely present a temporary, polluting alternative to burning PVC and creating dioxins. As an interim strategy, land disposal of PVC in a hazardous waste landfill may be preferable to incineration, but it poses its own environmental and public health threats and does not provide a long term secure solution to PVC waste management. Avoiding the generation of PVC-containing waste is the only sure way to prevent the problems associated with either landfill disposal or incineration of PVC waste.

RECYCLING MENACE
PVC Undermines
Recycling Efforts

MAJOR FINDINGS

O   Contrary to popular belief, recycling of PVC
    is negligible, with estimates ranging from
    0.1% to 3% of post-consumer PVC waste
    being recycled.

●   PVC is very difficult to recycle because the
    many additives used in PVC products make
    it impossible to retain the unique properties
    of the original formulation from a batch of
    mixed PVC products collected for recycling.

O   PVC severely impacts the recycling of PET
    plastic bottles due to difficulty in separat-
    ing these plastics when they are mixed
    together, and because of the contamination
    caused by the chlorine in PVC when they
    are processed together for recycling.

O   The vinyl industry has inflated its PVC recy-
    cling rate by failing to account for all PVC
    waste generated and by redefining PVC
    waste incineration as recycling.

O   PVC increases the toxic impacts of the recy-
    cling process for other discarded products
    such as nylon carpet, computers, automo-
    biles and corrugated cardboard.

The ability to recycle used PVC products into new
products is not feasible as a practical matter (Plinke
2000). While the vinyl industry has argued that PVC
can be recycled (VI 2004a, PP 1999), in reality, a neg-
ligible amount of PVC is actually recycled. Estimates
of how much post-consumer PVC (PVC that was used
by a consumer for its intended purpose) is recycled vary
from a high of about 3% (Plinke 2000, PP 1999) to a
low of less than 1% (Denison 1997, Beck 1996).
USEPA reports that less than 0.1% of PVC in post-
consumer municipal solid waste was recycled in 2001,
the most recent year for which data are available
(USEPA 2003). As discussed below, at most 0.3% of
PVC bottles were recycled in 2001 (Anderson 2004).

The primary reason for these poor recycling rates is the
lack of uniformity in the composition of PVC products.
Vinyl products are made using various formulations
that are designed to achieve certain properties and cre-
ate specific products. To achieve these features, addi-
tives such as lead, cadmium and phthalates that
enhance properties such as durability and plasticity are
mixed together with PVC. For example, vinyl siding
and windows are made with lead to make them more
durable, whereas infant chew toys contain phthalates
to make them more soft and pliable. Table 9 shows
what portion of the PVC is made up of these additives.

When these different formulations of PVC are mixed
together, such as when they are collected as part of a
recycling effort, they cannot be readily separated which

○ ○ ○ **Table 9** ● ○ ○

Typical Composition of PVC Products and Materials

Application	Share of the Components (weight - %)				
	PVC Polymer	Plasticizer	Stabilizer	Filler	Others
Rigid PVC Applications					
Pipes	98	—	1-2	—	—
Window Profiles (lead stabilized)	85	—	3	4	8
Other profiles	90	—	3	6	1
Rigid film	95	—	—	—	5
Flexible (soft) PVC Applications					
Cable installation	42	23	2	33	—
Flooring (calander)	42	15	2	41	0
Flooring (paste, upper layer)	65	32	1	—	2
Flooring (paste, inside material)	35	25	1	40	—
Synthetic leather	53	40	1	5	1
Furniture films	75	10	2	5	8
Leisure articles	60	30	2	5	3

Source: Prognos 1994, Prognos 1999, Totsch 1990 as cited in Plinke, 2000.

is necessary to reprocess the PVC back into its original formulation and to retain the unique properties of the original formulation (Plinke 2000, Thornton 2000). This problem is further complicated because PVC formulations for the same materials have changed over time.

There are other problems with mixing PVC with other plastics. One difficulty is color. Recycled products must be separated by color, which in most cases is not practical (Plinke 2000). Another difficulty is that soft PVC cannot be used in rigid PVC applications, and rigid PVC cannot be used in soft PVC applications since the material has to be reformulated (i.e., new additives need to be added). Thus, when different formulations of PVC are mixed together, it becomes virtually impossible to create a formulation that can be used for any application that requires specific properties.

As a result, a lower quality PVC plastic is produced which cannot be used for the same purpose as the original product (Plinke 2000). Thus, PVC can never be truly recycled into the same quality material. It usually ends up being made into lower quality products with less stringent requirements such as speed bumps, parking bumpers, or park benches. The loss of quality in a material during recycling is called "downcycling." The downcycling of plastics is common because of the difficulties in separating out the components with different additives (Plinke 2000). PVC that is downcycled does not reduce

the overall demand for the raw materials (virgin resin) used in making plastic, and has no effect on the amount of vinyl produced each year (Denison 1997).

In Europe, where PVC recycling has received greater attention, the vinyl industry has claimed greater progress in PVC recycling than is actually the case. Instead of measuring recycling progress against the total amount of PVC waste generated, the industry instead limited its recycling goals to the much smaller fraction of PVC waste that they deem to be economically "collectable" and "available." With this distortion the European industry claimed that they achieved their goal of recycling 25% of PVC waste window frames, pipes and fittings, and roofing membranes by 2003. In fact, actual PVC recycling rates were less than 5% for pipes and fittings, 6% for roofing waste and 16% for window frames (ENDS 2004).

The PVC industry's distortion of its recycling progress can't hide the facts. Throughout Europe, the total amount of PVC recycled in 2003 was 2% to 3%, matching only one-fifth of the industry's modest goal of recycling 10% to 15% of all PVC (not just what's collectable and available) by 2010 (ENDS 2003). These modest gains are being rapidly overshadowed by the projected 50% to 80% increase in PVC waste generation over the next twenty years (ENDS 2003, ENDS 2004).

Compare the 2% to 3% PVC recycling rate in Europe (which far outpaces the 0.1% to 3% U.S. PVC recycling rate) with the recycling rates for other commonly discarded products in the United States in 2001: auto batteries (94%), yard trimmings (57%), steel cans (50%), aluminum beer and soft drink cans (49%), paper and paperboard (45%), PET #1 plastic soft drink bottles (36%), tires (31%) and glass containers (21%) (USEPA 2004c).

To further cover its poor recycling record, the vinyl industry has taken to re-labeling PVC waste incineration as recycling. For example, the European Council of Vinyl Manufacturers describes trials of several new PVC "recycling" technologies. These include PVC waste incineration at a Dow Chemical plant in Leipzig, Germany to recover hydrochloric acid, and the chemical processing of waste PVC and mixed plastics to help fuel a steel plant in the Netherlands (ENDS 2003). They also included a proposed PVC waste gasification plant to make hydrochloric acid and a fuel gas, which was later abandoned by Solvay in France due to costs and technical problems (ENDS 2003). High temperature processing of PVC waste will form chlorinated

dioxins and furans and other toxic byproducts and can only be properly classified as incineration or waste treatment, not recycling.

Impacts on the Recycling of Other Materials

The difficulty in separating PVC from other plastics, such as polyethylene terephthalate (PET) bottles or nylon carpet facing, makes it extremely difficult, if not impossible, to recycle those otherwise recyclable materials. PVC also increases the toxic impacts of recycling of other valuable commodities such as copper from wiring and cable used in electronics like computers, steel from the scrapped automobiles and corrugated cardboard containers sealed with PVC tape. These examples are summarized in Table 10 and discussed below.

Plastic Bottles

PVC severely impacts the recyclability of other plastics such as polyethylene terephthalate (PET or sometimes PETE). Bottles made of PET and high density polyeth-

○ ◎ ⊛ Table 10 ⊛ ◎ ○
PVC Contaminates the Recycling of Many Materials and Products

Material and Product	PVC Use	PVC as Contaminant
Polyester from PET plastic (#1) bottles[1]	PVC and PET bottles are commingled in all bottle recycling efforts	Due to similar densities, it is difficult and expensive to separate PVC from PET; the presence of even a little PVC ruins PET recycling during processing.
Nylon facing from carpets[1]	Backing of carpet	PVC can't be readily separated from nylon; it contaminates it and results in "down-cycling."
Copper from wires and cables of electronics[2]	Plastic sheathing of wires and cables	The PVC on wires and cables with low copper content are burned at secondary copper smelters releasing dioxins and toxic additives and by-products.
Steel from automobiles[3]	Undercoating, wiring, interior and exterior trim, other plastics in autos	After shredding, most non-metal "fluff" is landfilled, but some PVC mixed with the steel is burned in electric arc furnaces.
Cardboard from boxes[4]	Tape and other binders used to seal boxes	After separation from corrugated cardboard, PVC plastic is burned at the paper mill.
Scrap wood from C&D[5]	Siding, pipes, window frames, flooring and other building materials	PVC scraps contaminate the waste wood extracted from C&D waste which is chipped to burn as a cheap fuel in "biomass" boilers.

Sources: 1 - Anderson 2004; 2 - SVTC 2004; 3 - CCC 2004; 4 - SCC 1988; and 5 - MDEP 2004a.

ylene (HDPE) make up 95% of all plastic bottles compared to only about 2.3% for PVC bottles (Anderson 2004). PET bottles (recycling code #1) are commonly used to contain water, soda, vegetable oil and many other products (Anderson 2004) and are highly recyclable. Lower quality recycled PET (which has greater tolerance for contaminants such as PVC) is often used to make a polyester fabric known as "fiberfill" that is used in coats, sleeping bags, pillows and carpeting. However, higher quality recycled PET (containing very little PVC) is increasingly being recycled directly back into bottles. It also has an economic benefit as it is sold for fiber at seven times the price of PET contaminated with PVC (Anderson 2004).

When PVC is mixed together with PET or other highly recyclable plastic, such as in the "all-bottle" recycling programs favored by the plastics industry, the few PVC bottles likely to be collected will be virtually indistinguishable from PET containers due to their similar appearance and density. Sophisticated separation technology that uses optical systems is available to identify and remove unwanted plastic bottles, such as PVC (USEPA 1993). However, the effectiveness of these systems is greatly reduced when the bottles are damaged or dirty. This makes accurate readings difficult to achieve and as a practical matter separation of PVC almost impossible (USEPA 1993, Anderson 2004).

If the PVC cannot be separated from the PET, it will severely effect the processing of the PET bottles into reusable plastic resin. This is because PET and PVC behave very differently when they are processed for recycling. PVC burns at a lower temperature than PET. It burns at the temperature that simply melts PET (Anderson 2004, EAF 1993). When this occurs, "black spots" get into the PET resin contaminating the batch and ruining or seriously downgrading the quality of recycled PET residue (Anderson 2004). According to one plastics recycler, "introducing one PVC bottle into the recycling process can contaminate 100,000 PET bottles" (Anderson 2004, EAF 1993). In addition, when PVC is melted, it generates hydrochloric acid, which will damage the processing equipment (OSWM 1993).

Despite these difficulties, the vinyl industry partially subsidized PVC bottle recycling in the mid-1990s (Anderson 2004). This effort failed miserably. At best, barely 2% of the bottles were recovered (Anderson 2004). Instead, truckloads of PVC plastic waste were landfilled (Denison 1997) leading the Association of Post-Consumer Plastic Recyclers (APR), a recycling industry trade group, to declare that vinyl products are "unrecyclable contaminants" in the recycling of PET

and HDPE bottles (PMF 2003). APR later abandoned its efforts to establish viable markets to recycle PVC (RT 2001). A report on the recycling of PVC waste prepared for the European Union similarly concluded "mechanical recycling is not qualified to contribute significantly to the management of PVC post-consumer wastes in the next decades..." (Plinke 2000).

More recently, a report released by the GrassRoots Recycling Network (a group of community activists and recycling professionals advocating for zero waste and sustainable communities) concluded that PVC bottle recycling is negligible today and that at most 0.3% of PVC bottles were recycled in 2001 (Anderson 2004). The report provides details of how PVC recycling of bottles does not exist, cannot exist, and is not wanted even by the plastics recycling industry. The only solution is a total phase-out of PVC and a rejection of programs encouraging curbside pickup of PVC that ultimately cause more harm than good.

Electronics

An estimated 26% of the plastic used in electrical and electronic equipment is made of PVC (MCTC 1996). The cabling of computers and other electronics is currently a major application of PVC in electronics, although it can be found in the housings of older computers that may still enter the waste stream (SVTC 2004).

When these consumer products reach the end of their useful life, components can be recovered and reused. Recyclers strive to recover valuable metals, such as copper from the wiring of these electronics. This is done by mechanical removal of the plastic sheathing, but it is only economical when the copper content is high. Most PVC cables from consumer electronics do not contain enough copper and so are bundled and shipped to a secondary copper smelter. Once there, the PVC plastic is burned off from the copper, a known catalyst of dioxin formation. Thus, recovery of copper wire results in toxic emissions including dioxins and furans to air and ash (SVTC 2004, USEPA 2001).

Smelting can present dangers similar to incineration. A report on the recycling of computer parts raised concerns that the Noranda Smelter in Quebec, Canada, where much of the North American "electroscrap" is sent, is "producing dioxins due to the residual presence of PVC or other plastics in the scrap" (SVTC 2004). Noranda has denied that this facility presents a "pollution hazard." Secondary copper smelters, such as the one operated by Noranda, have been identified as one of the highest sources of dioxin emissions in the U.S. (USEPA 2001).

Automobiles

Cars currently produced in North America average about twenty-four pounds of PVC per vehicle, according to plastics manufacturers (APC 2004). When the hulks of old cars are shredded, some of the PVC plastic mixes with the scrap metal which is melted down to make recycled steel. The high temperature and possible metal catalysts trigger formation of dioxins and furans. The vinyl industry advocates burning the plastics-rich automotive shredder residue (ASR or "fluff") either with municipal solid waste or in a cement kiln (VI 2004b). This will further contribute to dioxin formation from the chlorine present in automotive vinyl materials and formation of toxic PVC by-products (Singhofen 1997, CCC 2004).

The main uses of PVC in automobiles include underbody coatings and sealants, wire harnesses, dash boards, door panels, arm and head rests, upholstery, heating and cooling ducts, floor mats, spray-on sound deadener, seat belt latches, seat covers, mud flaps, and exterior trim such as body side protection strips, weather strips and window sealing profiles (APC 2004, VI 2004c, CCC 2004). PVC is the second largest volume plastic for automotive use in North America (APC 2004).

Carpets

The disposal of carpets in municipal and construction and demolition waste adds PVC from carpet backing to the solid waste stream. Two progressive companies controlling just ten percent of the market have achieved a modest 22% recycling rate for PVC carpet backing. But mechanical separation used by companies such as Interface Fabrics leaves too much PVC contaminant in with the nylon. PVC burns at the same temperature that nylon begins to soften and destroys the separated nylon fibers (Anderson 2004). Another company that uses recycling (Collins & Aikman) must downcycle the entire carpet to a lower value carpet backing, losing the nylon fibers for reuse and requiring virgin materials for new carpet facing (Anderson 2004).

Truly closed loop recycling for carpets, in which the facing and the backing fibers are recycled back into their original uses, remains elusive (Anderson 2004). And the modest success earned by recycling of PVC carpet backing can't be readily translated to other uses of PVC. The carpet makers enjoy a large volume, steady supply of discards with a relatively standard formula of PVC, unlike the variable PVC mixtures used in so many other far-flung products that are difficult to collect and recycle for a high end use (Anderson 2004).

Old Corrugated Cardboard (OCC)

Another use of PVC is to make packing tape that binds corrugated cardboard boxes. After this cardboard is used, it is broken down and returned to a paper mill for recycling. Any tape or plastic binding used to seal the cardboard is removed and separated from the cardboard, and then burned in the mill's industrial boilers. When this tape or binding is made of PVC and burned, another source of dioxin is created (SCC 1988). The Smurfit-Stone Container cardboard recycling facility in Missoula, MT processes up to 525 tons of old corrugated cardboard (OCC) per day. This mill generates about 15 to 25 tons per day of "OCC rejects" that consist of plastic packing tape, plastic twine and other non-cardboard contaminants, some of which is made of PVC (WVE 2002). Dioxins and furans have been identified in the air emissions of pulp and paper mills (USEPA 2004d).

Scrap Wood

Pressures are increasing to burn more scrap wood for fuel and power in so-called "biomass" boilers that are a proven source of dioxin emissions (MDEP 2004). Yet it is increasingly likely that PVC siding, window frames, roofing foils and other vinyl building materials will become mixed with scrap wood recovered from construction and demolition debris. When chipped and burned, this PVC-contaminated wood scrap is likely to add to the amount of dioxins formed.

DON'T BUY IT
Safer Alternatives to PVC are Available, Effective and Affordable

MAJOR FINDINGS

- PVC is the most environmentally harmful plastic; many other plastic resins can substitute more safely for PVC when natural materials are not available.

- Safer alternatives to PVC are widely available and effective for almost all major uses in building materials, medical products, packaging, office supplies, toys and consumer goods.

- PVC alternatives are affordable and already competitive in the market place.

- In many cases, the alternatives are only marginally more costly than PVC, and in some cases the costs of the alternative materials are comparable to PVC when measured over the useful life of the product.

- Phasing out PVC in favor of safer alternatives is economically achievable.

- A PVC phase-out will likely require the same total employment as PVC production (an estimated 9,000 jobs in VCM/PVC resin production, and 126,000 jobs in PVC fabrication) by making the same types of products from safer plastic resins.

Safer alternatives to the use of PVC plastic are widely available, effective and affordable. These alternatives pose fewer toxic chemical hazards than those associated with the manufacturing, use and disposal of PVC. In many cases, they completely avoid the formation of chlorinated by-products of combustion, e.g., dioxins, because they are chlorine-free; they also prevent the release of other harmful chemicals because they do not contain additives such as phthalates, lead, cadmium or tin, which are commonly found in PVC formulations.

Safer alternatives to PVC come in several forms including natural materials, as well as other synthetic plastics that are cleaner than PVC. For instance, instead of a vinyl shower curtain, a cloth shower curtain, wood clapboard siding or glass door easily does the job. For some people, the perceived aesthetic value of these natural materials further outweighs the comparative appearance of the PVC products. For others, the perceived convenience of lower maintenance tips the balance in favor of synthetic materials.

Even so, other cleaner plastics will do the same job as PVC without the high degree of toxic impacts throughout their life cycle. For example, a polyurethane-coated nylon shower curtain will repel water as well as one made of vinyl. The newly marketed polyethylene-based plastic siding avoids the toxic impacts associated with vinyl siding.
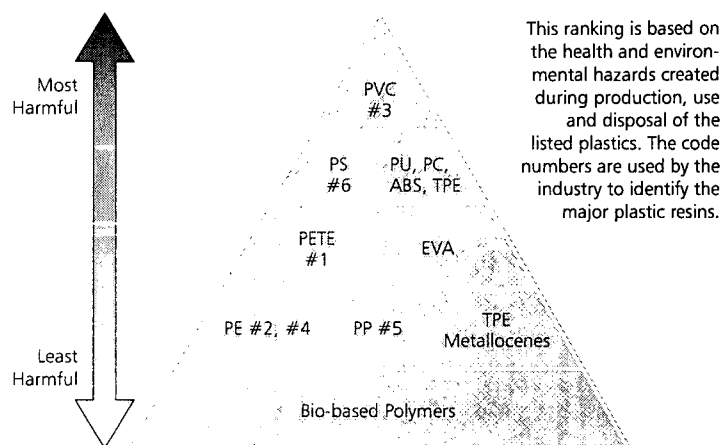
Many Other Plastic Resins are Safer Than PVC

Not all plastics or synthetic polymers are created equal. In a study of all major packaging materials conducted for the Council of State Governments in the U.S., PVC was found to be the most damaging of all plastics (Tellus 1992). A life cycle analysis conducted by the Danish EPA found that common plastics, such as polyethylene, polypropylene, polystyrene, PET and ethylene-propylene synthetic rubber, were all clearly preferable to PVC in terms of resource and energy consumption, accident risk and occupational and environmental hazards (Christiansen 1990).

This ranking of the major plastic resins from most harmful to least harmful is reflected in a revision of the Plastics Pyramid, originally developed by Greenpeace, shown in Figure 4 (DEPA 1995, van der Naald 1998, Tickner 1999a). The ranking qualitatively accounts for the toxic chemical hazards associated with the manufacture, use and disposal of plastics. Similar in concept to the federal government's Food Pyramid, the most harmful items at the narrow top of the pyramid should be avoided or used sparingly, while liberal advantage should be taken of the least harmful items listed at the broad base of the pyramid.

PVC clearly ranks as the most harmful plastic due to its high chlorine content, the toxic intermediate compounds used to produce PVC, the many toxic additives routinely added and its toxic by-products of combustion. PVC products, especially bottles and packaging, are sometimes labeled with the code number "3" (or the letter "V") based on a system used by the plastics industry to distinguish among the major plastic resins.

PVC   V   vinyl

Figure 4. A Plastics Pyramid

This ranking is based on the health and environmental hazards created during production, use and disposal of the listed plastics. The code numbers are used by the industry to identify the major plastic resins.

Most Harmful

Least Harmful

PVC #3

PS #6   PU, PC, ABS, TPE

PETE #1   EVA

PE #2, #4   PP #5   TPE Metallocenes

Bio-based Polymers

A key to the plastics and some hazards associated with production, use and disposal

Level 1	PVC = Polyvinyl chloride	Chlorine, intermediates, many additives, byproducts
Level 2	PS = Polystyrene	Intermediates, fewer additives, some byproducts
	PU = Polyurethane	Some chlorine used, intermediates, waste byproducts
	ABS = AcrylonitrileButadieneStyrene	Hazardous intermediates, difficult to recycle
	PC = Polycarbonate	Some chlorine used, intermediates, toxic solvents, BPA
	TPE = Thermoplastic Elastomer	A copolymer or alloy of conventional plastic
Level 3	PETE = Polyethylene terephthalate	Some hazardous chemicals, high recycling rate
	EVA = Ethyl vinyl acetate	Chloride catalyst, some byproducts
Level 4	PE = Polyethylene	Fewer additives, some byproducts, high recycling rate
	PP = Polypropylene	Fewer additives, some byproducts
Level 5	Bio-based Polymers	Naturally based, e.g. starch, cellulose; compostable

Sources: DEPA 1993, van der Naald 1998, Tickner 1999a.

The next level of the pyramid lists plastics that are still harmful but less so than PVC. These include polystyrene (PS), used for plastic cups and utensils and to make Styrofoam, and polycarbonate (PC), used to make compact discs and most reusable water bottles. PC releases a chemical known as bisphenol A (BPA) which is known to interfere with the functioning of the hormone system in lab animals and, as an endocrine disruptor, may pose a hazard to human health (Colborn, 1996). Acrylonitrile Butadiene Styrene (ABS) and polyurethane (PU) are also hazardous, but they are less toxic, persistent, and bioaccumulative than PVC.

The plastics in the middle of the ranking are even less hazardous than PVC and the other plastics higher on the pyramid. These include the polymer most often found in plastic beverage bottles, including bottled drinking water, known as polyethylene terephthalate (PET or PETE) (code # 1). Although hazardous chemicals are involved in the production of PET, it is recycled at a relatively high rate for plastics (19%) (USEPA 2003), especially in the eleven states that have

a returnable deposit on the sale of bottles of beer, wine, soda and other beverages.

Two high volume synthetic plastics are found near the base of the pyramid because they are far cleaner than PVC. These are polyethylene and polypropylene. Although these are both synthetic resins derived from nonrenewable fossil fuels, they are produced without toxic intermediates and far fewer additives or toxic by-products. Polyethylene, which ranks first in production among all resins, comes in two major versions: high density (HDPE or # 2), which is widely used in many applications, and low density (LDPE or # 4), which is commonly used in plastic bags. Both types are highly recyclable. Polypropylene (PP or # 5), often used for containers for products such as yogurt and prescription drugs, can readily be recycled but few recycling markets have been developed.

Even more environmentally preferable are the bio-based polymers, which are derived from natural renewable materials such as cornstarch or cellulose and which can be composted into beneficial organic matter to enrich soils rather than landfilled or incinerated. The Interface Fabrics company, among others, is pilot testing textile fibers made from bio-based polymers. An even higher standard would give preference to bio-based plastics developed from sustainable agricultural practices (e.g., without the use of pesticides and minimal fossil fuel inputs) that do not rely on genetically modified organisms or displace food products from serving the marketplace. Genetically engineered products should not be used in making bio-plastics.

Minimizing the disposal impacts of PVC favors the use of natural organic-based materials whenever practical because they biodegrade and represent a renewable resource. In many cases, however, a durable man-made plastic offers unique advantages to alternatives made of organic matter, minerals or metals.

Fortunately, as Figure 4 shows, many other synthetic plastic resins are widely available for product manufacturers to choose from to avoid the harmful impacts of PVC. And the emergence of bio-based plastics in the commercial marketplace gives an even greater boost to the success of sustainable production and environmentally preferable purchasing.

Safer Alternatives to PVC are Widely Available and Effective

PVC-free alternatives are already widely available for many applications. Several extensive reports have identified available and affordable alternatives to PVC (Ackerman 2003, Thornton 2002, Greenpeace 2001). Table 11 provides a few examples of available PVC-Free alternatives for several common PVC products. The sources reviewed below provide specific guidance on which vendors currently provide alternatives to specific products representing some of the most common uses of PVC. Several of these resources are searchable online databases of PVC-free products. The alternatives described can be currently found in the marketplace and are functionally equivalent, i.e., are as effective as a PVC product for the specified end use.

Building Materials

Effective alternatives are available now for most construction-related uses of PVC. Several databases, such as those offered by the Healthy Building Network (HBN 2004: http://www.healthybuilding.net/pvc/alternatives.html) and Greenpeace (Greenpeace 2004: http://archive.greenpeace.org/toxics/pvcdatabase), list these alternatives. A large number of construction projects, including the Sydney 2000 Olympic Stadium and the new EPA headquarters in Washington, DC have been constructed with little or no PVC (Greenpeace 2001, Greenpeace 2004b).

Medical Products

The Sustainable Hospitals Project is an excellent resource for healthy medical products, including PVC-free alternatives for gloves, bags and tubing. They operate a Website that includes extensive listings of products by category, by "hazard" or by manufacturer (SHP 2000: http://www.sustainablehospitals.org/cgi-bin/DB_Index.cgi).

Office Supplies

The Lowell Center for Sustainable Production has identified alternatives to the use of PVC in office supplies (SHP 2000: http://www.sustainablehospitals.org/cgi-bin/DB_Index.cgi). For example, instead of the common vinyl-coated three-ring binder, you can purchase an equivalent binder made of polypropylene with recycled content.

Packaging

The Grassroots Recycling Network has identified specific brand products that are currently packaged in PVC

◈ ◉ ◌ Table 11 ◌ ◉ ◉

PVC-Free Alternatives to Common Materials

PVC Product	Available Alternatives	Affordability
Automobile Components	Polyolefins[1]	Competitive for most uses[1,2]
Blinds	Wood[3], Aluminum[3]	Varies
Bottles	High Density Polyethylene (HDPE)[4] polypropylene (PP) Polyethylene Terephthalate (PET)[4]	Slightly more expensive. Costs expected to go down with increased market share.
Flooring (Hard)	Bamboo[5], Ceramic Tile[5] Recycled Glass Tile[5]	Bamboo is comparable to vinyl.[5] Ceramic and recycled glass are more expensive.[5]
Flooring (Resilient)	Cork[6], Stratica[6], Linoleum[6]	Alternatives cost more up front but last nearly twice as long. Savings of 30-50% over 20 years.[6]
Gloves	Nitrile[7]	Cost competitive when purchased in large quantities.[7]
Medical Bags, Tubing, Etc.	Polyurethane[7,8], Silicon[7,8] Polypropylene[7,8], Polyethylene[7,8]	Prices vary but most hospitals are able to negotiate comparable rates through high volume purchasing.[8] Prices will fall as market increases.[8]
Pipes	High Density Polyethylene[5,6,9] Copper[6,9], Cast Iron[5,9] Vitrified Clay[5], Concrete[9]	Decreased labor cost for installation reduces importance of price.[6,9] Pipe selection rarely determined by material cost differences in this industry[6,9]
Roofing (For Flat Roofs)	TPO- Thermoplastic Polyolefin[5] EPDM- Ethylene Propylene Diene Monomer[5]	Comparable to similar vinyl roofing[5]
Siding	Wood[6], Fiber Cement[6], Aluminum[5]	Varies - High quality, longer lasting materials can cost less than PVC if you shop wisely.[6] Aluminum is more expensive but very durable and maintenance free.[5]
Wallpaper	Natural Fiber[6]	More expensive[5]
Windows	Wood[6], Aluminum[6]	Varies widely[6]

Sources and Notes: 1 - Greenpeace 2001; 2 - Singhofen 1997; 3 - Dickey 2002; 4 - GRRN -2004; 5 - CEC 2004; 6 - Ackerman 2003; 7 - Ruzickova 2004; 8- SHP 2000; 9 - Harvie 2002. **Note:** This table is not meant to be exhaustive, as there are endless uses of PVC. Rather, it is provided to offer a few concrete examples of available and affordable alternatives to PVC. In choosing alternative materials for this table, an effort was made to exclude those having significant environmental and/or health concerns of their own. This does not imply an endorsement by CHEJ or EHSC of any materials listed. We do believe, however, that the materials listed offer an improvement over PVC. For any material, there are advantages and disadvantages and we would encourage you to thoroughly research all purchasing decisions.

bottles (GRRN 2004a: To view their list online, go to http://www.grrn.org/pvc). The market share of PVC for containers has steadily declined to about 2% of all bottles sold (Anderson 2004). The mostly widely used PVC-free alternatives for plastic bottles are high density polyethylene (used for milk products and almost all personal and household care products) and PET (used for most beverages and vegetables oils, for example).

Toys and Other Consumer Products

Greenpeace has established a Website that provides information on PVC alternatives for more general con-

sumer items, including toys. This site includes a toy-company report card that rates companies on a scale of 1 to 5, from being completely PVC-free to refusing to change policies or provide information (Greenpeace 2003, Greenpeace 1997: http://archive.greenpeace.org/comms/pvctoys; a more recent 2003 version can be found at http://www.greenpeaceusa.org/features/details?item_id=526899). It is worth visiting each site as they both contain unique information. Greenpeace also has issued a report on worldwide PVC restrictions that includes a list of companies, by country, that have made a decision to phase out the use of PVC in their products (Greenpeace 2001: http://archive.greenpeace.org/toxics/reports/restrictions.pdf).

Automobiles

Many automobile makers are beginning to find and implement alternatives to PVC. General Motors, the world's largest auto manufacturer, was the first to make a public statement of its intention to stop using vinyl. GM planned to end the use of PVC in car interiors by 2004, cutting total PVC use by 30% (CCC 2004: http://www.cleancarcampaign.org/pvc_elvbackground.s html). Also, other automakers, while remaining less public, have taken similar steps. Daimler Benz has not used PVC for interiors or undercoating in Mercedes autos since 1995 and Honda said they would gradually replace PVC in interiors by 2003 (Greenpeace 2001). Pontiac has found a unique way of applying polyolefin skin for full instrument panel design, instead of PVC. Likewise, Mitsubishi has substituted polyolefins in its instrument panels and door trimmings (Greenpeace 2001). According to the Clean Car Campaign—a national campaign coordinated by state, regional and national environmental organizations promoting a clean revolution in the motor vehicle industry—Volvo, Nissan, Toyota, and BMW are all using alternative materials to PVC in various applications and to varying degrees (Singhofen 1997). And according to the Greenpeace Review of Restrictions and PVC-Free Policies Worldwide, "Ford world-wide has set itself and its suppliers the ambitious target to eliminate applications of PVC by the 2006 model year" (Greenpeace 2001).

Appendix A to this report lists some common products available on the market that may contain PVC, including which products are bottled or packaged in PVC containers. Used with the resources reviewed above, consumers can easily leverage this knowledge to identify and replaced their purchases of PVC with safer alternatives. Also available is a list of specific products packaged with PVC (GRRN 2004a: http://www.grrn.org/pvc).

PVC Alternatives are Affordable

The following section on the affordability of replacing PVC with safer alternatives was derived primarily from the report "The Economics of Phasing Out PVC," written by Frank Ackerman and Rachel Massey of the Global Development and Environmental Institute, Tufts University, December 2003 (Ackerman 2003). This section was adapted from the above report with permission of the authors. The references used by the authors are cited in the original report which can be found in its entirety at www.ase.tufts.edu/gdae/Pubs/rp/Economics_of_PVC.pdf.

The serious health and environmental impacts caused by the production, use and disposal of PVC raise two important economic policy questions.

1) Are there affordable alternatives to replace most uses of PVC?

2) What would be the economic impact on society if PVC were phased out?

The Tufts University Global Development and Environment Institute addressed both of these questions in their recent report *The Economics of Phasing Out PVC* (Ackerman 2003). This report found that alternatives to PVC do exist and that PVC does not offer enormous economic advantages over other materials.

PVC-free alternatives are already competitive in the market place. The Tufts researchers found affordable alternatives available in every commercial and institutional PVC market they evaluated, including pipes, roofing materials, flooring, medical gloves, siding and windows (Ackerman 2003). Because PVC is found in so many products, the alternatives also widely differ depending on the product. The estimated costs of phasing out specific PVC products will likewise differ from one product market to the next. Many manufacturers and suppliers have been identified who currently sell cost-comparable alternatives to PVC used in medical bags and tubing, office supplies and building and construction materials.

The Tufts report concluded that a PVC phase-out is achievable and affordable and that it would not place a large burden on the economy. The study finds that the advantages of PVC are often overstated, that PVC is not substantially cheaper than many alternatives, and that alternatives providing equal or better performance are available for almost every use of PVC. In some cases, the costs of the alternative materials are already comparable to PVC when costs are measured over the

useful life of the product. In other cases, the alternatives are slightly more costly in today's market, though they are likely to come down in cost as their market share expands. There are "good reasons to expect the costs of alternatives to decline over time." The report also found that the continued use of PVC offers small short-term gains in some areas, and none at all in others.

The Costs of Replacing PVC: Three Studies

The Tufts report identified three detailed studies, all published in the mid-1990's, which estimated the costs of phasing out PVC. All three studies found PVC to be only modestly cheaper than the alternatives. The first study, conducted by the U.S.-Canada International Joint Commission (IJC) for the Great Lakes, examined the cost of phasing out PVC as part of its 1993 "Strategy for Virtual Elimination of Persistent Toxic Substances." This report was written for the IJC by a Canadian consulting firm, the Hickling Corporation, and updated in 1994. Charles River Associates (CRA), a U.S. consulting firm under contract to the Chlorine Institute, conducted the second study. This report, which was prepared in response to the IJC report, provided an economic analysis of the benefits of chlorine and related chemicals and included an analysis of PVC. The third study, conducted by Environment Canada in 1997, evaluated the options for replacing chlorine-based products and included a detailed look at the alternatives to PVC (Ackerman 20003a).

Each of these studies evaluated many specific uses of PVC and compared the prices of PVC products to their PVC-free alternatives. Environment Canada created two sets of price comparisons: a low cost case based on the least expensive available alternative and a high cost case based on higher-priced alternatives. Table 12 provides a summary of the estimated costs of replacing PVC made in each of these three studies. The table shows the cost increase that would result from switching to PVC-free alternatives, expressed in dollars per pound of PVC produced (updated to 2002 prices) for each study. Cost estimates are shown separately for pipes and for all other products since pipes represent about half of all PVC use. The

pipe and non-pipe figures in Table 12 were averaged to obtain a rough estimate of the total cost of replacing PVC.

According to the Tufts report, this table shows that there was a remarkable degree of agreement between the Hickling and CRA studies. These studies found nearly identical average costs for replacing PVC—$1.07 to $1.15 per pound. The Environment Canada low estimate had an average cost of about half this much, due to its lower estimate for pipe costs. For the non-pipe uses of PVC, there also was fairly good agreement between CRA, Hickling and the Environment Canada low estimate ($0.87 to $1.10 per pound). The data shows that PVC is only modestly cheaper than the alternatives. The Environment Canada study, which included the full cost of installation, found alternative materials would cost just 6% more than vinyl, and building a PVC-free home would increase the cost of a home by just 0.4 percent—increasing the cost of a $150,000 home to $150,600 (CIS 1997, Thornton 2000).

Factors Favoring Phase-Out of PVC

According to the Tufts report, cost estimates such as those made by Environment Canada, based on current market prices, tend to overstate the economic benefits of PVC. Four reasons were given for this conclusion.

1) Life Cycle Costs Often Favor Alternatives.

Some of the alternatives have higher initial purchase prices than PVC products, but are actually less expensive over the useful life of the product. The total cost

● ● ◉ Table 12 ● ◉ ◉ ◉ ◉

The Cost of Replacing PVC
US dollars per pound of PVC (2002 prices)

	CRA (industry)	Hickling (for IJC)	Environment Canada Low	Environment Canada High
Pipes	$1.43	$1.03	$0.15	$0.33
All other uses	$0.87	$1.10	$0.94	$3.84
Average	$1.15	$1.07	$0.55	$2.08

Average is the unweighted average of pipes and "all other uses."
Hickling data excludes windows.

Source: Ackerman 2003

over a product's life cycle is the cost that ultimately matters to the user. For example, the maintenance and repair costs for some building materials, such as flooring, can be the largest cost of a product's life cycle. In such cases, the lowest maintenance product is often the cheapest on a life cycle basis, regardless if it has the lowest purchase price. In this example, PVC or vinyl flooring is the cheapest option for commercial and institutional flooring on an initial cost basis, but among the most expensive options on a life cycle basis. When full life cycle costs are taken into account, PVC flooring loses out to alternatives that may have a higher initial price but last longer and are more easily maintained (Ackerman 2003).

2) Mass Production Reduces Costs.

Most products are cheaper when they are produced in large quantities. Costs typically drop as production volume increases. Currently, the advantages to mass production favor PVC, as many PVC products are produced in huge volumes. However, the production of the alternatives could likewise grow in volume in the future, making them less expensive and more competitive than they are at present. There are also learning curves that affect costs over time. As an industry gains experience with a production line, "bugs" are worked out, process improvements develop, and maintenance procedures and schedules are improved. All of these factors help to reduce costs.

3) PVC Products Endanger Their Users.

As previously discussed, the harmful effects of PVC are sometimes felt by the users of the products. For example, plasticizers in flexible PVC products such as children's toys can leach out of the product during use posing health hazards to users (see Chapter 3).

The Impact of a PVC Phase-Out on Jobs

The Tufts report examined the impact that phasing out PVC would have on jobs. Using data provided by the Alliance for Responsible Use of Chlorine Chemistry (ARCC), they estimated that there are approximately 126,000 workers in PVC fabrication plants and approximately 170,000 workers at chlorine-producing and chlorine-using chemical plants in the U.S. However, most of the chlorine workers are in non-PVC related chlorine sectors such as paper mills, pesticides, and solvents. The Tufts researchers estimated that only about 9,000 of the 170,000 workers were employed in the production of vinyl chloride monomer (VCM) and PVC resin.

The Tufts report identified 12 operating VCM plants in the U.S. as of 2000, with a capacity to produce 17.4 billion pounds of VCM. According to the report, seven of the facilities that account for more than half the capacity were jointly located with PVC plants owned by the same company. The report also showed that as of mid-2003, ten companies produced 15.8 billion pounds of PVC resin at twenty locations in the U.S. Three other plants were idled by the recession with an additional capacity of 1.2 billion pounds.

The Tufts report suggested that replacing PVC with safer alternatives will change some of these jobs: from fabricating PVC products to fabricating the same products from other materials, most often other plastics; or from making vinyl chloride and PVC resin to making safer substitutes. However, the alternatives are likely to require about the same total employment as production of PVC. In some cases, the same workers who currently make PVC products will be employed making products from PVC alternatives (Sources: Ackerman 2003 and Ackerman 2003c).

4) Environmental Protection Costs Are Routinely Less than Anticipated.

History has shown that the actual costs of compliance with environmental standards are often lower than the originally predicted costs. One of the best examples of this occurred in the PVC industry in 1974 when the Occupational Safety and Health Administration (OSHA) established a strict standard for workplace exposure to vinyl chloride, the raw material used to produce PVC. When this standard was proposed, the vinyl industry claimed that the costs of compliance would be in the "billions" and that the industry might shut down. Instead, actual costs were only a fraction of the original estimates primarily because the industry developed new

cost effective technologies to comply with the regulation. Other studies have confirmed this pattern of over-estimating compliance costs (Ackerman 2003b).

In summary, the Tufts report concluded that a "PVC phase-out is achievable and affordable. The alternatives are increasingly well known and well developed, and in many cases are already cost-competitive with PVC. It is realistic and practical to build health and environmental considerations into materials choices for municipal infrastructure, commercial and residential buildings, medical supplies and consumer products. The cost impacts of substitution will be modest and will grow smaller over time" (Ackerman 2003).

TAKE ACTION
Preventing Harm from
PVC Use and Disposal

RECOMMENDATIONS

- Policy makers at the local, state and federal level should enact and implement laws that steadily reduce the impacts of PVC disposal and lead to a complete phase-out of PVC use and waste incineration within ten years.

- A new materials policy that embraces aggressive source reduction of PVC should be adopted to steadily reduce the use of PVC over time.

- Federal and state waste management priorities should be changed to make incineration of PVC waste the least preferable disposal option.

- In the interim, any PVC waste generated should be diverted away from incineration to hazardous waste landfills.

- Consumers should take personal action to buy PVC-free alternatives and to remove PVC from their trash for management as household hazardous waste.

- Communities should continue to organize against PVC-related dioxin sources such as waste incinerators while working to promote safer alternatives.

Personal and political actions must be taken to prevent harm to human health and the environment from the use and disposal of PVC. If we don't burn PVC, the formation of dioxins and other toxic by-products of combustion will be prevented. If we can reduce the flow of PVC to landfills, leaching of toxic additives will be avoided. If we promote and purchase safer alternatives to PVC whenever they are available, then toxic pollution will be prevented throughout the PVC life cycle.

Making Choices: A New Materials Policy for PVC

When solid waste experts in the U.S. first established meaningful management goals about fifteen years ago, there was universal support for source reduction as the top priority (USEPA 1989). Table 13 shows the priorities established by the USEPA for the most environmentally sound strategies for managing solid waste. Source reduction is the top choice. It means taking action to avoid or prevent waste from being generated in the first place. In keeping with this philosophy, the first priority in managing PVC waste should be to avoid making it or using it in the first place.

We should adopt a universal policy and practice across the country to avoid the purchase or use of PVC whenever possible in order to prevent waste management problems before they start. We need to dramatically

⌣ ○ ◉ Table 13 ◉ ○ ⌣

National Priorities for Solid Waste Management

Highest Priority	SOURCE REDUCTION	Includes Reuse
Middle Priority	RECYCLING	Includes Composting
Lowest Priority	DISPOSAL	Includes both Combustion and Land Disposal

Source: USEPA 2004d, USEPA 1989

and steadily reduce the amount of PVC waste produced through a source reduction strategy that targets PVC-containing products.

The second best option, if generating waste can't be avoided in the first place, is to reuse, recycle and compost the wastes. With PVC waste, this is not an option. Most PVC products cannot be reused or recycled, and definitely will not compost. What is the best option for PVC waste after source reduction and recycling? The answer lies in defining what ultimate disposal strategy is preferred once PVC waste has unavoidably been generated.

Federal solid waste policy fails to express a preference between waste disposal in incinerators or in landfills, treating each as equally usable options (See Table 13). Consistent with this lack of judgment, the USEPA has failed for over 12 years to finalize its reassessment of the health risks from exposure to dioxins. In addition, the USEPA has failed to take aggressive action to prevent dioxins and other toxic pollutant releases at their source, such as working to reduce PVC use and disposal.

Some states have chosen incineration as their top waste management option, favoring even dirty mass burn facilities over landfill disposal. For example, as shown in Table 14, under Maine state law, waste incineration is preferred over landfill disposal (MRSA 2004a). The State of Maine, in turn, burns the highest proportion of its waste (after recycling) of any state in the country (see Table 7 in Chapter 5).

By favoring waste incineration, such policies encourage the continuous formation of dioxins and other toxic air emissions, and the generation of toxic ash requiring land disposal. The burning of PVC in municipal solid waste releases dioxins and toxic additives. Land disposal, on the other hand, minimizes dioxin formation by avoiding intentional combustion, although some highly polluting landfill fires are unavoidable. Land disposal additives in PVC will leach and eventually contaminate groundwater. However, this is also true for incineration, since a large amount of dioxin and metal-laden incinerator ash also requires land disposal.

We believe that a new health-based materials policy is needed to reorder current federal and state priorities for waste management. Such a health-based policy should be designed so that the greatest effort is invested in the highest priority options as shown in Table 15. We propose a new set of priorities for PVC waste management that are based first and foremost on targeted source reduction steps that will prevent the creation of PVC waste in the first place. This strategy aims to aggressively and continuously replace the most hazardous uses of PVC with safer alternatives whenever available.

These source reduction steps include immediate action

⌣ ◉ ◉ ○ Table 14 ◉ ◉ ◎ ◈ ⌣

The State of Maine's Waste Management Policy Favors Incineration Over Landfill Disposal

Highest Priority	SOURCE REDUCTION	Includes reducing both the amount and toxicity of the waste
2nd Priority	REUSE	
3rd Priority	RECYCLING	
4th Priority	COMPOSTING	Of biodegradable waste
5th Priority	INCINERATION	And other waste processing which reduces waste volume
Lowest Priority	LAND DISPOSAL	

Source: MRSA 2004a

● ● ● **Table 15** ● ● ●

Proposed Priorities for PVC Waste Management

Highest Priorities	Step # 1 - SOURCE REDUCTION	Ban disposable PVC bottles, containers and packaging.
	Step # 2 - SOURCE REDUCTION	End the use of lead and cadmium in all PVC products.
	Step # 3 - SOURCE REDUCTION	Phase out all disposable, non-durable uses of PVC.
	Step # 4 - SOURCE REDUCTION	End the use of PVC products containing phthalates.
	Step # 5 - SOURCE REDUCTION	Phase out PVC uses that are vulnerable to fire hazards, e.g., in building materials and cars.
2nd Highest Priority	EXTENDED PRODUCER RESPONSIBILITY	Require manufacturers to finance the "take-back" and safe management of PVC products at the end of their useful life.
3rd Priority	REUSE AND RECYCLING	Achieve the low potential to recycle bulk PVC waste into the same type products.
4th Priority	LAND DISPOSAL	In the interim, divert any unavoidable PVC waste away from incineration for disposal in hazardous waste landfills.
Last Option	INCINERATION	Ban open burning and incineration of any waste containing PVC

to end the use of PVC bottles and packaging. Other source reduction targets would include short-lived disposable PVC products and those that contain lead, cadmium and phthalates. Fire-vulnerable uses of PVC in buildings and vehicles should be replaced with safer alternatives. To avoid toxic by-products generated during structural fires, vinyl siding, roofing and window frames among other uses, should be replaced with safer alternatives.

This health-based materials policy would favor land disposal over incineration only temporarily and only for legacy waste from the stock of current PVC in use and any other unavoidable PVC waste. This waste would be managed by land disposal in a hazardous waste landfill.

A new materials policy for PVC defines incineration as the least favorable waste disposal option. We need to create effective systems to collect and divert PVC in

the waste stream away from incineration. PVC should be actively managed as a serious problem waste akin to handling household hazardous waste (or other non-hazardous problem wastes like propane tanks or latex paint). This would mean educating consumers to identify PVC waste and separate it from the waste stream. As an interim practice, PVC should be diverted away from incineration for collection and transfer to a triple-lined "secure" hazardous waste landfill. With time, after PVC has been replaced with safer materials, the need to divert PVC to landfills would diminish.

Our vision for managing PVC waste is positive. We promote safer alternatives to PVC that are effective, affordable and available now. Alternatives that exist for most uses of PVC are able to do the job well at a cost that is comparable to PVC. Substituting safer materials for PVC is consistent with principles of clean, sustainable production (see Chapter 8).

To realize steady progress on the path to a PVC–Free Future, many personal and political actions by many people will be necessary.

Personal Steps

Taking personal responsibility for preventing harm from PVC is an important place to begin. Here are some key actions you can take as a consumer and contributor to generating household PVC waste.

1. Identify PVC Products.

Look for the "# 3" or the letter "V" inside the plastic recycling symbol (or sometimes beneath the recycling symbol) on the bottom of bottles and on clear plastic packaging such as blister packs. The # 3 and the letter V indicate that the plastic is made from PVC. Also, look for the words "PVC" or "vinyl" on the product (e.g., plastic pipe) or on its packaging. You will need to use other strategies to identify PVC products that are not labeled. Does the unlabeled soft plastic, such as the skin on a 3-ring office binder or a shower curtain, have that "new car smell" of chemicals? If so, it's probably vinyl and you're breathing phthalates, a PVC additive. Check the PVC product listing in Appendix A for likely suspects. You can also call the company and ask them whether they use PVC. If they do, ask them to switch. If they don't, thank them for being environmentally conscientious.

PVC   V   vinyl

2. Buy and Promote Safer Alternatives.

Search for and purchase non-PVC alternatives (see Chapter 8). Always avoid PVC bottles and plastic wrap (e.g., Saran Wrap). Consult Internet resources on PVC-free alternatives for office supplies, medical supplies, toys and building materials (see Chapter 8). Educate others about PVC hazards. Promote safer alternatives in your homes and business, with your friends and neighbors. If the best alternative is a plastic, look for the cleaner plastics, such as polyethylene (# 4 or # 2) or polypropylene (# 5) (See Figure 4).

3. Start Collecting PVC.

Don't toss PVC in the household trash, especially if your garbage is incinerated (see Table 7 to see if your state relies heavily on burning its waste). Put the PVC aside in an enclosed cardboard box and/or garbage bag away from the sun and possible ignition sources. See how much PVC you can salvage and segregate from the waste stream. Every bit of PVC diverted away from incineration will prevent some dioxin formation.

4. Ask the Manufacturer to Take it Back.

If you can identify who made the product containing PVC, bundle it up in a secure cardboard box and mail it back to the Chief Executive Officer of the product manufacturer (search the Internet for the address of the corporate headquarters and the CEO's name). Enclose a polite note asking that they take personal and corporate responsibility for safely managing this problem material at the end of its life. Tell them you won't buy any more of their products until they make the switch to PVC-free manufacturing. Warn them not to burn it. Ask them to dispose of it at a hazardous waste landfill or to securely store the PVC unless they can recycle it for high value uses. Ask for a written response.

5. Dispose of Your Collected PVC as You Would Household Hazardous Waste.

If you have too much PVC waste to mail back, ask that your community household hazardous waste collection program accept PVC plastic for secure hazardous waste land disposal, not for incineration. Explain the reasons why PVC is a serious problem waste. Encourage others to separate and divert PVC away from incineration.

Community Action: People, Voices and Communities

Being a PVC-free consumer is not enough. The real power needed to adopt a new health-based materials policy for PVC lies in the number of people involved. When friends and neighbors work together to organize their community to take action, major changes can occur. Grassroots action by community groups around the country has already stemmed the damage from PVC use and disposal. Medical waste incinerators are rapidly being replaced due to community-based campaigns that promote non-incineration alternatives (see case studies in Chapter 5). Few new municipal waste incinerators have been sited in the last ten years due to environmental health concerns and community opposition.

CASE STUDY

Intimate Brands Responds to 6,000 Consumers and Stops Using PVC

Greenpeace and the Center for Health, Environment and Justice (CHEJ) teamed up in 2001 to launch a consumer campaign against a major beauty supply company who distributed products packaged in PVC containers. The Victoria's Dirty Little Secret campaign successfully targeted Intimate Brands, the parent company of Victoria's Secret and Bath & Body Works, who agreed to phase-out PVC containers from their product line by the end of 2003 after receiving 6,000 faxes, phone calls, and postcards in one month.

Organizers launched the campaign at an Eco-Conference held annually on college campuses, distributed flyers and postcards, and posted an action alert allowing Website visitors to fax a letter or send a postcard directly to Intimate Brands. The company initially responded by sending defensive letters to the individuals that wrote to them. However, as more letters continued to come in, they took the demand more seriously. In February 2002, they met with representatives from CHEJ and Greenpeace and presented a plan to phase out the use of PVC bottles in both their Victoria's Secret and Bath & Body Work's line. PVC bottle production would stop by 2003 and by 2005 all PVC bottles would be out of circulation. The effectiveness of this campaign is a testimony to the positive changes that can be made when people come together and pressure companies to put safety first (Source: Lester 2003).

Community action has also repeatedly changed national waste policy from the grassroots up. Join with your friends and neighbors to make a difference. Join a local group or start a new one to take action against dioxin sources such as incinerators, backyard burning, landfills, biomass plants or building fires where PVC use and disposal release toxic chemicals into the environment. For referrals and how-to tips, contact the Center for Health, Environment and Justice (www.chej.org).

Organizing To Win Around Issues on PVC

Every day, people facing threats to their health and environment speak out about PVC problems. They look for proof that a landfill leaks, or seek to undertake a health study to link emissions from an incinerator to cancer, or find evidence that a polluting company has a bad environmental record. However, simply speaking the truth

about landfills, incinerators, toxic products or previous violations won't stop the poisoning of our bodies and the environment.

The truth is only a start. In order for things to change, the truth has to be understood by a large group of people who then use this knowledge to fuel their efforts to win justice. The truth won't stop the poisoning, but mobilizing and organizing will.

According to Webster's dictionary, organizing is "uniting in a body or becoming systematically arranged." Organizing to protect our communities from environmental harm means pulling together a large enough, diverse enough, active enough group of people to convince corporations and the government that they have to stop making people sick with toxic chemicals.

Organizing is how we restore the balance between the rights of people to safe products and healthy communities, and the rights of corporations to profit. We will never have as much money as the corporate polluters. We will never be able to afford their Madison Avenue media campaigns or their twenty-four hour access to elected officials. But we can build our own power to overcome their influence. We can do this by organizing to demonstrate the strength of our numbers and the righteousness of our demands.

Successful organizing happens when a group of people find visible ways to use the truth to wake up the conscience of a larger group. In an era when politics is defined by scandals and sound bytes, organizing can remind the American people that political life is supposed to be about self-government, justice and the common good.

After years of doing it, we've come to the conclusion that organizing is more of an art than a science. At the same time, there are some basic rules for organizing that usually hold true. These rules aren't always applicable, but they are right often enough that you should consider them if you start to get organized around an environmental issue in your community.

Basic Organizing Rules

Power determines the outcome.

If two or more groups care about an issue, and one of them has a lot more power, that group will get what it wants, no matter what the facts are or who will be hurt.

Our power comes from people, while corporations and government's power comes from money.

Communities need to use strategies that depend on people's creativity, courage and caring. The corporations and government will use strategies that depend on things that can be paid for, like experts and lawyers.

Polluters and government agencies write the rules so they can win using experts and lawyers, which are their strength.

You can assume going in that if you play exactly according to the rules of their game, you will lose most of the time, whether you are at the slot machines in Atlantic City or the hearing process of your state environmental agency. Create your own rules instead.

To win, communities will have to work harder than polluters and government agencies do.

Polluters and agencies are doing what they do because they are paid to. They've done it before, and they know most of the facts before the fight even starts. You are opposing them because you believe your health and your community are at risk. This gives you an unmatched motivation for working harder than they do.

These rules may seem harsh and they are. And sometimes things turn out to be easier than these rules would lead you to expect. But when your community is at stake, it's important to start out vigilant, alert and ready to face the challenges ahead.

Experience has taught us that organizing isn't easy. Recognizing this should help you to be forgiving of each other and ourselves. We are trying to build a democratic society without adequate blueprints and models, so our trial-and-error method has to leave room for experimentation and mistakes. And recognizing how necessary organizing is should help you to be inclusive and persistent. There are no magic facts. There are no perfect heroes to give perfect speeches that will convince the polluters to stop polluting. There is only the dogged determination of people working together to

protect their own health, their families' health and the health of their communities. This is why we organize. (See below for "Ten Simple Steps To Organizing.")

Mobilizing vs. Organizing

What is the difference between mobilizing and organizing? Take the 2004 protests in New York City around the Republican Convention. There was a large mobilization—demonstrations that brought out over 800,000 people—and various targeted actions. The main goal was to influence the results on Election Day and get people to understand the issues.

Mobilization is a thing that good organizers do. Mobilization is getting people together, moving people out. It's bringing people in to do an action. It's using everything including phone calls, personal visits and handing out fliers to bring a certain level of consciousness to the community. When trying to change policy and public opinion and purchasing choices, you need to use both organizing and mobilizing.

As a result of a mobilizing initiative, you will likely find people who will join your organization and build your organization's base. However, most people who are mobilized are not likely to join but their voice/presence in an activity increases your power for that moment. You are not likely to know how folks got to the mobilizing activity. Maybe they saw it listed on the internet at MoveOn.org or received an e-mail flyer, or a friend agreed to have dinner with them afterwards if they met at an event.

In organizing, leaders understand how people got there. For an organizer it would be important to have 100 people at a demonstration and to know exactly how those people got there. You know which leaders talked to people and can talk to them again, not just for this one event, but maybe for another campaign. Think about how to use mobilization opportunities to move your issues and to identify new members for your organization.

Ten Simple Steps To Organizing

1. Talk and Listen

If you are one, two or three individuals without an organization, you'll need to talk with other people in your community to build a group. If you are already part of an organization, then your next step is to talk to the people in your organization about initiating a campaign around a PVC issue in your community. Brainstorm a list of groups and individuals whose interests are most directly affected by PVC, then determine who you need to talk with first. Who are the people that are most directly affected? Who are the leaders in that neighborhood? What other organizations are involved in protecting the community's health? You can work out the answers to these questions in a brainstorming exercise at an early meeting of your group. Brainstorm a list of the groups of people whose self-interests are most directly affected, then figure out who has contacts with these groups or individuals.

2. Create and Distribute Fact Sheets

Create an attractive, easy-to-read and accurate fact sheet to educate the community about the problems and how these problems relate directly to their lives. A simple one-page fact sheet will serve the purpose.

3. Recruit Hundreds, One At A Time

Recruiting will help you build the relationships, resources and critical mass to act effectively for change. Reach out to a wide range of local groups to build the broadest possible coalition. It will be much more difficult for decision-makers to ignore your concerns if your campaign represents a wide cross-section of your community. All recruiting is a form of door knocking. If you are trying to organize a neighborhood, the doors line the streets. If you are trying to build a different kind of group or coalition, the doors may spread all over town and you may need appointments to open them. There are several ways to make knocking on doors easier. First come up with a 'rap'— "I am..." "We are..." "This is..." "We want..." "You can..." Also, consider circulating a petition. Not only will the petition help you get the names and addresses of community supporters and show community support to those in power, it also begins the process of getting the people you're talking with involved in the issue. Make sure to listen closely to the concerns of the people you are talking with and link the PVC problem to their interests and concerns.

4. Hold Meetings That Make People Want to Come Back and Bring Their Friends

People will come to a meeting if:

- They have made a commitment to come
- They have a role or responsibility in the meeting
- They have an immediate and specific self-interest in the work of the organization
- They have past, positive experiences with similar meetings

To have a successful meeting, your recruitment efforts must satisfy the first and third of these conditions. The second and fourth conditions will depend on how you run the meeting. There are several different kinds of meetings to suit different purposes.

House Meetings - This is the kind of meeting many groups hold when they are first forming. The meeting is held at a member's house and the style is informal. One of the biggest benefits of this kind of meeting is the greater comfort level among members.

Planning Meetings - Leaders or other key decision makers within the group get together to set their agenda, review the work that's been done and plan activities. Planning meetings should not be decision-making meetings, but rather they should establish the agenda and process by which decisions will be made at a general membership meeting or define a plan to carry out an activity that has already been decided upon by the membership.

General Membership Meetings - These meetings are important to ensure that all members of the organization share the responsibility for decision making and carrying out the activities of the organization. The time and location should always be chosen to accommodate the maximum number of people. The meeting should always start with an agenda and when possible, get the agenda out to people prior to the meeting in the form of a flier (this will also serve as a reminder for the meeting). Make sure you pass around a sign up sheet to collect names and addresses to contact people who attended in the future.

People will come to the next meeting if they enjoyed the first one, if it started and ended on time and wasn't a bore, if it produced concrete results, if it was lively and exciting, and if it delivered what was promised.

5. Set Goals

It is critically important to have long-term, intermediate and short-term goals to help members understand where they are going and the steps they have mastered along the way. Ask yourselves: What do we want? What is your bottom line? Do you want to pass a local or state law that bans PVC products where alternatives are available? This could be your long-term goal.

Next identify different strategies and tactics that will lead you to your goal such as getting your city or county council to pass a resolution to phase out all PVC products where alternatives are readily available. This could be your intermediate or short-term goal.

6. Identify Your Targets

Once you've identified what it is that you want, the next step is to identify who can give it to you. Pinpoint the actions and the people that have the power to help you reach your goal. The people who impede the achievement of your goal are often referred to as the targets of the campaign. This does not mean that they are evil or bad. It simply means that because they have the power to give you what you want, it makes sense to focus your attention and actions on them. The target of your campaign must always be a person or persons. You can't fight City Hall because City Hall is a building, but you can target the person with the power at City Hall to get them to act.

To help your group identify your targets, answer these three questions.

● Who is responsible for the situation you want to change?

● Who can make the changes you want to happen?

● How can you convince them to act on your issue?

7. Research Is An Essential Tool

Research is a tool, not an end product. You need to do research to gather enough information to achieve your goals, not to know absolutely everything there is to know. Research should tell you who has the power to give you what you want and should help you figure out what arguments your targets will probably use against you. Once you know this, you can create counter arguments. This report will give you some of the information you need, but you need to undertake the local research related to the problem that you want to address.

8. Take Direct Action

An action is any step you take to advance your group's goals. Petitions, letter-writing campaigns and educa-

tional meetings are all actions that advance your group's goals. A direct action is the most dramatic type of action, involving confrontation and demands. Direct action begins after your efforts at education, information sharing and persuasion are ignored. Use direct action when your group is ready to confront a decision-maker with its frustrations and to make specific demands. Direct actions move your organization outside the established rules for meetings and discussion. It takes your group into a forum in which you make the rules and where elected representatives and corporate executives are less sure of themselves and how to handle the situation. A direct action often provides the necessary pressure to force your target to act on your group's issue.

9. Target The Media

Who are the media decision-makers who need to be convinced that your story should be covered? What will it take to convince them? In most media outlets, the decision-makers are the editors, and the way you get to them is to spoon-feed them a story they can use without much work. It is important to develop a media strategy for your campaign that you can constantly refine and develop. But don't be fooled into believing that the media is the only way to get your story out. Keep creating your own media through fact sheets, cable access television programs, newsletters, call-ins to radio talk shows, letters to the editor, statements at public hearings, barbecues, rallies, auctions, concerts and videotapes.

10. Celebrate The Victories And Keep Applying Pressure

Savor the victories no matter how large or small. A meeting with the City Council is a small victory and a resolution to stop purchasing PVC is a larger victory. Celebrate all victories because it helps members to see that you are moving forward and are winning. No one wants to join a loser organization.

Policy Action

While personal steps are critically important, community action is a must. But neither are enough. The personal should also be political. Unless the system that unduly relies on hazardous materials like PVC is changed, then green consumerism and green behavior will remain a minor movement of the privileged few. Unless many community-based organizations join forces, large-scale systemic change will be slow in coming.

○ ○ ● Table 16 ● ○ ○
A PVC-Free Policy Action Agenda

Accomplish Within Three Years

1. Ban all open waste burning.
2. Educate the public about PVC hazards.
3. Ban the incineration of PVC waste.
4. Collect PVC products separately from other waste.
5. In the interim, divert PVC away from incineration to hazardous waste landfills.

Accomplish Within Five Years

6. Establish our Right-to-Know about PVC.
7. Label all PVC products with warnings.
8. Give preference to PVC-free purchasing.
9. Ban use of PVC in bottles and disposable packaging.
10. Ban sale of PVC with lead or cadmium.

Accomplish Within Seven Years

11. Phase out other disposable PVC uses.
12. Phase out other high hazard PVC uses.
13. If safer alternatives are not yet available, extend the PVC phase-out deadlines for specific uses.
14. Fund Efforts to reduce the amount of PVC generated through fees on the PVC content of products.

Accomplish Within Ten Years

15. Phase out remaining durable PVC uses.
16. Decommission municipal waste incinerators in favor of zero waste plans.

Here are a number of action steps that government at the state, local and national levels must take to phase-out PVC in a timely and orderly manner. Actions that may be successful early on and that establish a foundation for future PVC reductions are listed first in order on the timeline below. These policy actions also give guidance to other decision makers in industry, commerce and institutions about policies that they should embrace to help prevent harm from PVC use. This PVC-free action agenda is summarized in Table 16.

Accomplish Within Three Years

1. Ban All Open Waste Burning. Backyard burning of household trash and other open burning should be strictly prohibited everywhere as the country's major uncontrolled source of dioxin pollution. However, a statutory ban will not be effective without educating people about the hazards of PVC and simultaneously working aggressively to reduce the toxicity of the waste stream. People burn their waste to avoid real costs and inconvenience, and out of cultural habit and practice. People need to know the truth about PVC and waste burning in order to overcome their resistance to change.

2. Educate the Public About PVC Hazards. Conduct a well-funded public education campaign that targets PVC as a serious problem waste that especially threatens public health when burned, but also creates health and environmental risks when disposed of in a landfill. Use a hard-hitting approach that holds the chemical industry responsible for the impacts of open burning and for selling a material that releases toxic additives and by-products. Model the campaign along the same lines as the anti-tobacco industry ads that work to reduce teenage and adult smoking. The educational campaign should sell PVC-free solutions as it persuades people to halt the backyard burning of trash.

3. Ban the Incineration of PVC Waste. All forms of incineration of PVC waste should be phased out by a certain date. Designate PVC waste as hazardous waste. Develop educational programs and incentives to remove PVC from waste streams destined for incineration. Replace all medical waste incinerators with non-burn technologies for waste that needs to be disinfected and send the disinfected residue to a "secure" landfill. Develop a workable timeline to ban the incineration of PVC in municipal solid waste.

4. Collect PVC Products Separately from Other Wastes. Award grants and publicize new programs to support PVC waste separation and collection. Identify

CASE STUDY

PVC Identified as
Household Hazardous Waste

In its Plan for the Statewide Collection of Household Hazardous Waste, the State of Maine identified PVC as a problem waste that should be separately collected and, if not recycled, then diverted away from incineration to landfill disposal. Although household hazardous waste remains exempt from regulation, collection programs are being expanded in Maine and elsewhere to encourage residents to turn in old hazardous products for safe management rather than tossing them in the trash. In addition to spent paint thinner, old pesticides, mercury products and other toxic household waste, the Plan targets PVC, latex paint and old propane tanks as problem wastes requiring special collection and management. Efforts are underway to establish a reliable means of funding the operational costs of household hazardous waste collection so that this plan can be fully implemented in Maine (Source: MDEP 2001b).

CASE STUDY

San Francisco Bay Area Adopts
Dioxin-Free Purchasing Policies

The San Francisco Bay Area is leading the nation in preventing dioxin pollution by passing Dioxin Resolutions in Oakland and San Francisco and establishing dioxin-free purchasing requirements for local governments. The resolutions grew out of a grassroots campaign to shut down the last commercial medical waste incinerator in Oakland, one of the largest sources of dioxin in the Bay Area. A diverse coalition of environmental, environmental justice, health-impacted groups, labor representatives, and local government officials worked together to shut down the incinerator in 2001. In the process, they convinced local governments to pass dioxin resolutions and establish a Bay Area Government Task Force to implement resolutions that will:

◉ Promote dioxin pollution prevention practices;

◉ Use less toxic, non-chlorinated products and processes, such as chlorine-free paper and PVC-free plastics;

◉ Urge health care institutions to phase out PVC products;

◉ Work with other local governments to convene a Regional Task Force to identify sources of regional dioxin pollution and develop prevention strategies; and

◉ Pursue dioxin reduction practices that do not cause workers to become unemployed (Sources: Greenaction 2001a, CO 1999, CSF 1999).

PVC as a hazardous waste and add PVC waste products to existing programs that collect household hazardous waste, mercury products and other problem wastes for safer management.

5. In the Interim, Divert PVC Away from Incineration to Hazardous Waste Landfills. Clarify waste management priorities for PVC to establish preference for land disposal over incineration due to the formation of dioxin and other toxic by-products. Make the institutional arrangements needed to ensure that PVC waste is disposed of in "secure" triple-lined hazardous waste landfills and diverted away from incineration. Identify opportunities for operators of waste incinerators to remove more PVC waste from the floor of the incinerator prior to waste combustion.

Accomplish Within Five Years

6. Establish Our Right-To-Know About PVC. Require product manufacturers that sell products containing PVC to notify the state of the amount of PVC and the specific chemical name of additives used in individual products, identified by brand name, model and type of PVC use. This information should be made available on-line in a searchable database on PVC products that allows consumers and business people to identify PVC and its ingredients in consumer products and materials. This provides people with the knowledge they need to ask questions and make decisions about safer PVC-free alternatives.

7. Label All PVC Products with Warnings. A meaningful education and PVC diversion program will run head long into the current limits on identifying PVC in the

waste stream. By requiring all PVC products to be labeled, PVC can be more readily separated from other waste and diverted away from incineration. Warnings should encourage consumers to avoid burning PVC products. Labeling will also encourage product manufacturers to switch to safer non-PVC materials to avoid labeling requirements.

8. Give Preference to PVC-free Purchasing. A government procurement policy that establishes as a priority the purchasing of safer alternatives to PVC will harness institutional buying power. Changing the buying habits of various levels of government will help drive the market for PVC alternatives and begin to affect the practices of other institutions in the supply chain that supports government operations.

U.S. Companies Stop Using PVC in Products

Dozens of U.S. companies have stopped using PVC in their products. Some examples are as follows.

- General Motors announced it would phase out the use of PVC for auto interior panels by 2004, informing its suppliers to use alternatives for all new products (CCC 2004).

- Nine toy manufacturers, including International Playthings, Gerber and Brio are phasing out all the PVC in their products (Greenpeace 2003).

- Mattel, Inc., the world's largest toy manufacturer, is planning to phase in plant-based plastics to replace PVC in company products (Greenpeace 2001).

- NIKE, the shoe and sports equipment manufacturer, is phasing out PVC in its products (Greenpeace 2001).

- Helene Curtis eliminated PVC bottles for packaging Suave, and Intimate Brands, a major beauty supply company, is phasing out PVC containers by 2005 (Lester 2003).

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9. Ban the Use of PVC in Bottles and Disposable Packaging. These two uses of PVC are the easiest and most compelling to ban outright in the near term. Both represent short-lived uses that become PVC waste soon after purchase. The PVC in bottles contaminates the recycling of the more plentiful and safer PET bottles (# 1 plastic) (see Chapter 7). The market in PVC bottles has already been declining steadily. The growing use of PVC for packaging, such as in clear plastic blister packs, adds disproportionately to the problem of PVC in municipal solid waste. Safer alternatives for both uses are readily available and already in the market place.

10. Ban the Sale of Any PVC Containing Lead and Cadmium. The continued use of these two highly toxic PVC additives presents a serious hazard that has long been recognized by progressive governments. Even the PVC industry has moved to replace some uses of lead and cadmium as stabilizers in their products. For example, the European vinyl industry has set a voluntary goal to phase out the sale of lead stabilizers by 2015 with a 15% reduction by 2005 and 50% by 2010 (ENDS 2004). However, by 2003 only a 5.3 % reduction in lead had been achieved (ENDS 2004). We think the global PVC industry needs to move away from lead much faster. By banning the sale of any new PVC product containing lead or cadmium, policy makers will be acting on strong public health science. Such a ban will further clean up PVC and raise questions about the other additives used in PVC and the hazards of the material itself.

Accomplish Within Seven Years

Priorities for Replacing Specific PVC Uses

1. PVC bottles and disposable packaging
2. PVC containing lead or cadmium
3. Other non-durable disposable PVC uses
4. Other higher hazard PVC uses
5. Other PVC used in durable goods

11. Phase Out Other Disposable Uses of PVC. Non-durable products made with PVC become waste in short order, steadily adding PVC to the municipal waste stream. Separating PVC from the waste stream after it is generated will never be 100% effective. Nor can these collected non-durable PVC products be readily recycled. Therefore, the next phase in directing reductions in PVC usage should focus on replacing the remaining non-durable disposable uses of PVC with safer alternatives whenever they are available, effective and affordable.

12. Phase Out Other High Hazard Uses of PVC. A further priority should target replacement of PVC uses that expose sensitive groups of people to toxic additives and other uses that are vulnerable to dioxin-forming fires. The continued use of vinyl in medical products

Health Care Institutions Move to Phase Out PVC

⊙ Health Care Purchasing: Four top group purchasing organizations that buy supplies for more than 70% of U.S. health care facilities, such as Premier, Inc., established initiatives to reduce the purchasing of medical products containing PVC, mercury and the chemical plasticizer diethylhexyl phthalate (DEHP) (HCWH 2002a).

⊙ Baxter International, Inc., one of the world's largest medical supply manufacturers, is phasing out PVC in its intravenous (IV) solutions containers (Baxter 1999).

⊙ Abbott Laboratories has committed to move toward PVC- and DEHP-free alternatives (Abbott 2003).

⊙ The thirty-seven members of the Maine Hospital Association agreed to continuously reduce the use and disposal of PVC plastic in hospitals as part of a statewide pollution prevention agreement (MHA 2001)

CASE STUDY

Model Policy Action Taken to Phase Out PBTs and PVC

In 2000, the Washington State Department of Ecology (Ecology) developed a groundbreaking strategy to phase out some of the deadliest toxic chemicals in Washington—persistent, bioaccumulative and toxic chemicals (PBTs). Ecology's program has a goal of reducing PBTs such as mercury, dioxin, PBDEs (toxic flame retardants) and PCBs by the year 2020.

Under Washington's PBT strategy, chemical action plans are developed for high priority chemicals. In 2003, Ecology developed a plan to reduce and phase out mercury and the legislature passed a bill to ban certain mercury consumer products. Right now, Ecology is working on a chemical action plan to reduce and eliminate toxic flame retardants (PBDEs), chemical cousins of PCBs that are rapidly rising in the environment, breast milk, orcas and other wildlife.

The Toxic Free Legacy Coalition, led by Washington Toxics Coalition, Washington Physicians for Social Responsibility, Healthy Building Network, WashPIRG, Breast Cancer Fund and People for Puget Sound, is working to ensure the meaningful implementation of legislation and Ecology's PBT strategy.

On a local level, the Toxic Free Legacy Coalition was successful in getting the City of Seattle to adopt a first in the nation purchasing policy to reduce and eliminate the purchasing of products that contain or generate PBTs, including PVC. The hazards of PVC continue to be central to the debate surrounding successful implementation of the Resolution (Source: WTC 2004).

represents a prime example of unnecessary exposure to the additives in PVC products. DEHP, a type of phthalate additive, leaches out of vinyl medical bags and tubing. An infant boy in neonatal intensive care may be exposed to enough phthalates from PVC to pose harm to his developing reproductive organs (Rossi 2001). Examples of PVC uses particularly vulnerable to dioxin-forming fires include automotive applications and building materials such as vinyl siding. High fire hazard uses of PVC should be replaced with safer alternatives.

13. If Safer Alternatives are Not Yet Available, Extend the Phase-Out Deadlines for Specific PVC Uses. A reasonable PVC phase-out policy would make allowance for those few cases where acceptable alternatives are not readily available. In such a case, a temporary exemption could be granted for a scheduled PVC phase-out deadline upon a satisfactory demonstration by a product manufacturer. Further criteria for granting interim relief should consider whether the specific use of PVC is essential to public health and safety or if the available alternative does not work effectively or is much more expensive.

14. Fund Efforts to Reduce the Amount of PVC Waste Generated Through Fees on the PVC Content of Products. Funding will be needed for public education, developing diversion and labeling programs, and to administer an orderly phase-out of PVC products. PVC products should be assessed fees to pay for these PVC reduction programs. That's the fairest approach. Fees should be collected at the product distribution level to avoid the administrative burden of retail fee collection.

Accomplish Within Ten Years

15. Phase Out Remaining Uses of Durable PVC Products. The remaining uses of PVC should be relatively lower hazard uses in longer-lived products that have less chance of accidental combustion or public exposure to toxic additives. These uses should be replaced with safer alternatives as the final priority for the orderly phase-out of PVC. By ending all uses of PVC, the toxic impacts across the life cycle from production to disposal will be prevented.

16. Decommission Municipal Waste Incinerators in Favor of 'Zero Waste' Plans. Within ten years, we should replace the inherently dirty and obsolete strategy of needlessly burning valuable resources disguised as discarded materials and products. Zero waste strategies involving much more aggressive source reduction (including product redesign), reuse, recycling and com-

posting can reduce waste volumes even more than incineration, and without generating toxic by-products. As the contracts expire on the current inventory of more than 100 municipal solid waste incinerators, these plants should be safely decommissioned. Waste incineration should be relegated to the dustbin of history.

Conclusion

Within ten years, we can bring a virtual halt to the toxic life cycle of PVC. Through persistent organized action at all levels, discarding harm from PVC disposal will become a practice of the past. Safer alternatives will serve the same purposes filled by PVC now through the use of clean materials and the sustainable production of clean products. The health and environmental problems created by PVC can be solved through two profoundly simple actions—don't buy it, don't burn it!

APPENDIX A
Common Household Products and Packaging
That May Contain PVC

Thousands of consumer products and packaging are made from PVC. The following is a general list of some common products that are typically made of PVC This list is meant to be a starting point for identifying what common products are packaged in or made from PVC. In creating this list, we recognize that companies are always changing their products, including the materials they use to package them. In some cases, you may find that a product listed is no longer made from PVC. If this happens, you may want to contact the company and congratulate them for being environmentally conscientious.

While this list may help get you started, not all containers and products are labeled. If you suspect that a product or its packaging is made of PVC, we suggest you contact the product manufacturer and ask them directly about the materials used in the product or its packaging. One way to be sure if the packaging of a product is made from PVC is to look for the number "3" or for the letter "V" inside the universal recycling symbol. This means that the product is made of PVC. Soft flexible plastic products that are made with PVC often have a distinct odor. What you smell is the plasticizer that was added to the PVC material to make it soft and flexible.

PVC   V   vinyl

In addition, a list of specific products identified by brand name that are packaged in PVC bottles, was generated by the Grassroots Recycling Network (GRRN 2004a). This list can be accessed on the GRRN web site at http://www.grrn.org/pvc.

Apparel:
Boots
Aprons
T-shirts with PVC prints (shiny)
Raincoats
Rain pants
Skirts
Lingerie
Shoes
Bags
Luggage
Bibs
Backpacks (PVC coating for
    waterproofing)
Watchbands
Diaper covers

Personal Care Items (packaging):
Shampoo
Hair gel
Lotion
Suntan lotion
Baby oil
Mouthwash
Face Wash
Aloe Vera Gel
Massage oil
Liquid soap

Household Items:

Cleaning product containers
Waterbeds
Shelving
Checkbook covers
Photo album sheets
Self-adhesive labels and stickers
Shower curtains
Imitation leather furniture
Mattress covers
Textiles
Toys
Clothes racks (covers metal to
   prevent rusting)
Pet care product containers
Strollers

Kitchen Items:

Drinking straws
Tablecloths
Beverage containers
Plastic utensils
Dishwasher, refrigerator and
   freezer racks
Dish drying racks (covers metal
   to prevent rusting)
Appliance casings
Food wrap
Food containers

Outdoor Items:

Pond liners
Tarps
Greenhouses
Children's swimming pools
Inflatable furniture
Outdoor furniture
Garden hoses
Balls

Automotive:

Upholstery
Dashboards
Door panels
Underbody coating
Car seats for children
Traffic cones
Wire coating
Auto-related product containers

Building Materials:

Pipes
Siding
Tiles
Wall coverings
Window frames
Door frames
Door gaskets
Gutters
Fencing
Plastic lumber

Shutters
Flooring
Wire/cable insulation
Molding
Cavity closure insulation

Medical Supplies:

Colostomy bags
Catheters
Blood bags
Bed liners
Tubing
Gloves
Mattress covers

Office Supplies:

Computer keyboards
Computer monitor housing
Cellular phones
Floppy disks
Binders
Clipboards
Paper clips
Tape
Mouse pads

Miscellaneous:

Credit cards
Slide holders
Landfill liners and leachate pipes

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APPENDIX B
Amount of PVC Generated, Incinerated and Landfilled in Each State

State	Total MSW Generated (tons)	Total Amount of PVC Disposed (tons)[1]	Amount of PVC Incinerated (tons)[2]	Amount of PVC Landfilled (tons)[2]
Alabama	*	*	*	*
Alaska	*	*	*	*
Arizona	6,012,359	37,277	0	37,277
Arkansas	3,838,217	23,797	545	23,252
California	54,429,851	337,465	9,205	328,260
Colorado	5,051,132	31,317	0	31,317
Connecticut	4,734,132	29,352	16,257	13,095
Delaware	1,069,042	6,628	0	6,628
Florida	19,706,584	122,181	45,364	76,817
Georgia	11,214,006	69,527	350	69,177
Hawaii	1,706,018	10,577	3,454	7,123
Idaho	1,090,000	6,758	0	6,758
Illinois	15,951,037	98,896	0	98,896
Indiana	9,542,378	59,163	6,177	52,986
Iowa	3,416,268	21,181	366	20,815
Kansas	4,698,338	29,130	0	29,130
Kentucky	5,465,608	33,887	16	33,871
Louisiana	4,952,900	30,708	0	30,708
Maine	1,327,164	8,228	5,448	2,780
Maryland	8,904,464	55,208	12,486	42,722
Massachusetts	8,307,387	51,506	28,145	23,361
Michigan	16,916,076	104,880	8,639	96,241
Minnesota	5,043,752	31,271	14,432	16,839
Mississippi	2,918,407	18,094	0	18,094
Missouri	7,256,744	44,992	207	44,785
Montana	*	*	*	*
Nebraska	2,395,100	14,849	0	14,849

State	Total MSW Generated (tons)	Total Amount of PVC Disposed (tons)[1]	Amount of PVC Incinerated (tons)[2]	Amount of PVC Landfilled (tons)[2]
Nevada	3,365,570	20,867	0	20,867
New Hampshire	1,214,777	7,532	1,675	5,857
New Jersey	10,606,326	65,759	9,593	56,166
New Mexico	2,095,052	12,989	0	12,989
New York	24,775,000	153,605	37,517	116,088
North Carolina	8,981,349	55,684	842	54,842
North Dakota	638,804	3,961	0	3,961
Ohio	16,211,198	100,509	0	100,509
Oklahoma	4,489,028	27,823	0	27,832
Oregon	4,074,945	25,265	2,434	22,831
Pennsylvania	12,675,854	78,590	17,746	60,844
Rhode Island	1,248,745	7,742	0	7,742
South Carolina	5,973,059	37,033	2,004	35,029
South Dakota	518,493	3,215	0	3,215
Tennessee	7,365,920	45,669	1,266	44,403
Texas	28,531,660	176,896	0	176,896
Utah	2,471,404	15,323	782	14,541
Vermont	611,617	3,792	498	3,294
Virginia	10,877,723	67,442	18,806	48,636
Washington	8,666,755	53,734	4,606	49,128
West Virginia	1,754,523	10,878	0	10,878
Wisconsin	5,592,862	34,676	1,545	33,131
Wyoming	693,783	3,301	0	3,301
Totals	**369,381,411**	**2,289,166**	**250,405**	**2,038,761**

Sources and Notes: Estimates derived from Kaufman (2004) for 2002. (1) The amount of PVC generated in each state is derived by multiplying the total Municipal Solid Waste (MSW) generated in that state by the percent of PVC (0.62%) estimated from USEPA (2003). We assumed the percent of PVC estimated from the USEPA data was representative of the PVC content in a typical municipal solid waste stream and that none of the PVC was recycled. (2) The amount of PVC incinerated (or landfilled) in each state was calculated by multiplying the total PVC disposed of in the state by the percent of waste incinerated (or landfilled) after recycling. The percent of PVC incinerated (or landfilled) after recycling was determined by dividing the total amount of waste incinerated (or landfilled) in a state (provided in Table 4 of Kaufman 2004) by the total waste disposed of (after recycling).

* These states did not participate in the survey conducted by Biocycle magazine (Kaufman 2004).

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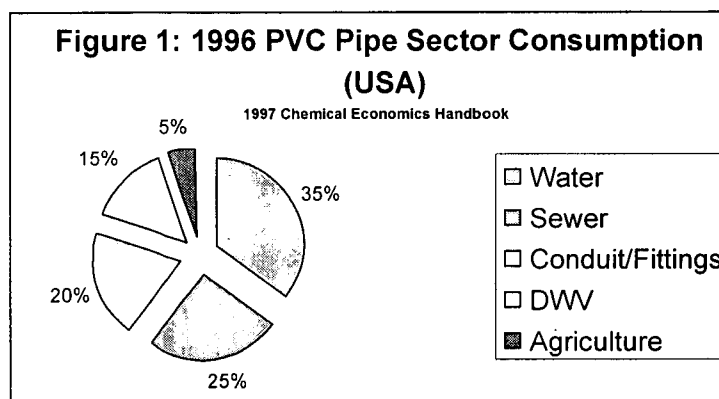by Jamie Harvie
with Tom Lent

1) Introduction

This report provides a preliminary analysis of polyvinyl chloride (PVC) free pipe materials in construction. PVC reduction and elimination has become a priority for many government institutions, healthcare organizations, and design firms due to the serious environmental health impacts associated with the lifecycle of PVC. The pipe market represents about 50% of total PVC use in the United States. In the effort to provide leadership on pollution prevention and the protection of environmental health, the significance of modeling PVC free alternatives cannot be understated.

Based on the inventory of PVC pipe use provided, there are readily available PVC free alternatives for all pipe applications, many with a longer history on the market than PVC. Primary alternatives include ductile iron, copper, high density polyethylene (HDPE), cross liked polyethylene (PEX), concrete, and steel. Project specific design conditions may make these alternatives either less or more costly than the comparable PVC, but in general the alternative materials are cost competitive. Familiarity with a particular material is a large driver in material choice. *

2) Summary of Pipe Sectors & Alternatives

The major pipe sectors are:
- **Water** – potable water delivery
- **Sewer** - sanitary (waste water transport outside of the building) and storm (site runoff transport)
- **Conduit /Ducting** – protection of electrical and communication wire, typically called conduit for above ground uses, and duct for below ground applications.
- **Drain/Waste/Vent** (DWV) - waste water transport within the building
- **Agriculture, Irrigation and Drainage** – water delivery for irrigation and ground drainage

Figure 1: 1996 PVC Pipe Sector Consumption (USA)
1997 Chemical Economics Handbook

- □ Water
- □ Sewer
- □ Conduit/Fittings
- □ DWV
- ▨ Agriculture

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* Note: Smaller thin walled piping, such as copper distribution, is often referred to as "tube" instead of pipe. The term "pipe" is used in this report to address both pipe and tube applications.

For each of the major piping sectors, there are a variety of alternative PVC free piping materials. This report will look at the primary alternatives (those alternative products with a large market share) in each sector using the premise that the marketplace has already determined which alternatives are most suitable and competitive to PVC.

The primary alternatives to PVC pipe in each sector are shown below in Table 1.

Table 1. Primary Alternatives to PVC by sector

Water	Ductile iron, HDPE, Concrete, Copper, PEX
Sewer	Concrete, HDPE
Conduit and Ducting	HDPE, Steel, Aluminum
Drain, Waste and Vent (DWV)	Cast Iron, Copper, ABS, PEX
Agriculture and Drainage	HDPE, Concrete

Adapted from Environment Canada report

ABS – Acrylonitrile butadiene styrene
HDPE – High Density Polyethylene
PEX – cross linked polyethylene

Acrylonitrile butadiene styrene (ABS) is not chlorinated, but like PVC has highly hazardous manufacturing intermediates, including carcinogens and is difficult to recycle. It is considered only marginally better than PVC environmentally.

High Density Polyethylene (HDPE) is available for all pipe applications. Being non-chlorinated, requiring fewer additives, and having a much higher recycling rate, it is considered a more benign plastic than PVC. PVC is more resistant to combustion, but smolders at a lower temperature than HDPE and releases toxic hydrochloric gases before combustion.

Cross linked polyethylene (PEX) is a polyethylene similar in many characteristics to HDPE but with molecules cross linked to improve its ability to handle higher temperatures.

Copper is highly recyclable but copper leaching into water supplies can be harmful to aquatic life. Copper also has significant life cycle problems in its mining and manufacture.

Concrete, iron and steel have significant embodied energy usage and their manufacture is not environmentally benign. However, all of them (with the exception of ABS) are generally considered environmentally superior to PVC. Aside from concrete, the primary PVC free alternatives are consistent with state government and professional association Environmentally Preferable Purchasing (EPP) guidelines (www.apwa.net/Documents/GovtAffairs/Policies/SolidWaste/solid-environpolicy.pdf). Steel, HDPE and copper pipe or conduit may all contain recycled content in the product. Quantities and post consumer content will vary with application and manufacturer.

3) Cost issues

A detailed cost analysis of the alternatives is beyond the scope of this report. It is important to note, however, that material costs for the pipe itself are frequently a relatively small fraction of the total project cost. While the pipe costs itself can vary considerably over time and geography due to market location and material/resin costs, there are a variety of other variable that can affect project cost. These include but are not limited to the experience and comfort level of the contractor with a particular pipe material, soil and other site conditions, installation method, and local labor costs which can have a dramatic impact on total pipe project costs. An analysis of PVC pipe alternatives by Environment Canada found that PVC alternatives are generally cost comparable. The costs of substituting for PVC pipe in the municipal pipe market represented 3% (high) and 1% (low) of total revenues from water and sewer rates. (http://www.on.ec.gc.ca/water/greatlakes/data/chlor-alkali/ A Technical and Socio-Economic Comparison of Options to Products Derived From the Chlor-alkali Industry).

Conversation with industry officials and literature review suggest that pipe material cost differences, to the extent that they do exist, are often not the determinant issue in pipe selection. In many instances in the pipe market, the choice of material has less to do with real cost differences and more to do with familiarity with one pipe type and a resistance to change. This is an important discussion in the context of value engineering. The fact that a wide range of PVC free materials have maintained significant market share in competition with PVC indicates that each of the alternatives already has broad market acceptance and demonstrated effectiveness.

4) Alternative materials comparison issues

The long-term durability of piping systems depends on many factors, including the soil environment, proper installation, material properties such as corrosion resistance, chemical resistance and strength and the performance of joints. (Env. Canada). Each of the primary PVC free materials have benefits that have kept them as significant market players.

A) Water
The water distribution piping market is typically divided into small diameter pipe (4" - 12") and large diameter pipe (14" - 36"). Smaller pipe and tubing (under 4") is used for distribution within buildings. Sewage pipe has been categorized into three size segments: small (4" - 15"), medium (18" - 36") and large sizes (over 36"). Small diameter pipe accounts for about 65% (by length) of total demand for pipe. See Table 2.

Systems are a tree-like pipe network consisting of:
Transmission lines - (water mains - typically 36" diameter or less)
Distribution lines - (lower diameter sizes: 6" - 12")
Service connections - (from street to building) 4" and less

Water mains typically operate at pressures from 100 to 150 lbs per sq. in. (psi), while distribution lines operate between 40 and 100 psi. Service connection lines are usually a diameter of 1" or less and can be made of various materials: polyethylene, PVC, iron or copper pipe. (Env. Canada)

Currently, PVC has a dominant share of the market for small diameter pipe in the water main (4" - 12"), sanitary sewer and storm sewer (4"-15") markets, while traditional materials (ductile iron and concrete)

continue to have majority market share in the larger diameter pipe. (Env. Canada). According to the Plastics News (July 16, 2001) the demand for large diameter pipe plastic pipe has increased 8.3% between 1990 and 2000.

The smaller tube sizes used for in building distribution are primarily split between PVC, copper, and iron. There is limited data on the breakdown of market share.

Polyethylene is just beginning to penetrate the market for all sizes.

The use of galvanized steel and polybutylene has declined due to corrosion problems with galvanized and catastrophic failures with polybutylene.

One of the key design concerns for drinking water infrastructure design and installation is leakage. When one turns on the tap for potable water, there is a cost associated with the acquisition, treatment, and supply (pumping) of the waster. If a water distribution system leaks, the lost water can become an extremely high cost. In arid areas, such as the American Southwest, where costs to acquire water can be exorbitant, leaks can be an expensive proposition. In Charleston West Virginia, a 4 inch leak in their 24 inch diameter iron pipe resulted in the loss of 3 to 5 million gallons of water per day. In Washington D.C, there is about 66 million gallons of water unaccounted for. (Plastics Pipe Institute Fall 2002)

HDPE has a slight advantage in leak resistance over PVC. This is because it can be delivered in longer lengths, minimizing the quantity of joints. Furthermore, the butt or electro-fusion processes used to join HDPE provides stronger, tighter, more leak proof joints compared to the bell and spigot joints used in PVC pipe for mains or the solvent glue joints used for smaller distribution. The longer length of HDPE can require longer trenches to be open at a time, but its length and flexibility can allow for trenchless procedures, particularly in sewer replacement. HDPE's greater flexibility and resilience (particularly at lower temperatures) also make it less susceptible to surge and hammer shocks or to damage from digging. HDPE's flexibility and resilience has made it increasingly popular in earthquake territory or other areas where soils can shift. For larger diameters, the fusion technique requires a fusion machine, which might be problematic in cramped spaces. For smaller diameter pipes, a handheld device can be used to weld/melt the pipe lengths together. Mechanical couplings are available for HDPE, though some of these couplings may be made of PVC.

PEX is another form of polyethylene that retains HDPE's flexibility and chemical resistance while providing resistance to higher temperatures for which HDPE is not suitable. It is coupled with either fusion techniques or mechanical crimp couplings. Due to its higher temperature ratings it was initially used in radiant and district heating system applications, but is now also beginning to be used more widely in water supply and gas distribution systems.

Ductile Iron (DI) has significantly higher tensile strength, making it more capable of handling higher pressures, crushes and hammer than PVC. DI does not lose strength at high or low temperatures as PVC does. Ductile iron is impermeable to hydrocarbons and other groundwater contamination unlike PVC or other plastic pipe.

"There has been much debate over the durability and expected lifespan of each of these materials. The life of a pipe system depends not only on the material, but the installation and the surrounding environment. All these types of pipe have been on the market for over 30 years, and while there are examples of pipe

failures for each of them, this study did not find conclusive evidence to suggest that one material has a significantly different lifespan from the other. When properly designed and installed, pipe systems of any of these materials can be sufficiently durable to withstand many decades of services." (Env. Canada)

B) Sewer

Prior to the 1960s most sewer systems were combined sewers, that is, carried both sanitary and storm water. The system had to be designed to carry large volumes of water during rain events, but otherwise the capacity was little used. In addition, when it did rain the flood of relatively fresh water often negatively impacted water treatment. Design changed so that by the mid 1960s sanitary and storm systems were designed and constructed separately. Storm sewers collect water from roof drains, parking lots and streets. Unlike sanitary sewers, storm wastewater is not typically treated and the flow is directly discharged into a receiving body of water.

Similar to water distribution use, PVC is dominant in the smaller size sewer pipe market with HDPE just beginning to seriously compete. These smaller lines are commonly used in the collection network of subdivisions. In this segment, the competing concrete pipe is non-reinforced concrete pipe in 8" and 10" sections. The smallest diameter reinforced concrete pipe is usually 12" pipe.

As in water main pipe, HDPE is a comparable alternative to PVC pipe in sewer systems. HDPE sewer pipes are also available in diameters ranging from 4 inches to 36 inches, although for storm sewer, much of the demand is for 10 to 15 inch, while for sanitary 8 to 12 inch are popular diameters. At larger diameters, the major market share is held by concrete, primarily due to cost.

C) Conduit and Ducting

Galvanized steel and aluminum are the traditional conduit materials. Over the last few decades PVC has been able to take a large share of this market. Over the last decade HDPE has seen the most growth in the conduit sector, and easily competes with PVC. There is limited data on the breakdown of market share. HDPE's extremely low coefficient of friction makes it easy to pull cable through; one reason for its increasing popularity. Fire code concerns have limited HDPE acceptance for indoor conduit applications making it the primary alternative to PVC for outdoor and underground applications. Steel and aluminum conduit are the primary alternatives to PVC for indoor applications. While PVC is fire resistant, it's tendency to smolder and emit hydrochloric gases before combustion is a particularly dangerous attribute in medium and high voltage conduit applications. HDPE comes in rolls of several hundred feet while PVC and metal conduits comes in rigid 20 foot sections. This makes HDPE easier to use for larger installations and metal easier for smaller installation. Some metal conduit products may be coated with PVC. It is important to specify those products that are PVC free.

D) Drain Waste and Vent (DWV)

Cast Iron and copper are the traditional DWV materials. PVC is widely used in residential construction because of the ease of joining with solvent glues. ABS and PEX have both become popular alternatives to PVC in more recent years. As previously noted, ABS has serious environmental problems of its own.

E) Agriculture, Irrigation & Drainage

A variety of alternatives to PVC are used both for water delivery and for drainage. Irrigation sprinkler, drip and drainage systems have long been available in HDPE and have significant advantages in resilience against compression, shovel attack and ground movement. Corrugated steel, concrete and HDPE are all competitive alternatives for drainage. HDPE drainage pipe is now available in formulations with high recycled content. Plastic pipe has carved a hunk of the huge market previously dominated by concrete and steel. Highway drainage is a fast growing market for HDPE. Recently, the Corrugated Polyethylene Pipe Association initiated a third party certification system which allows for increased acceptance of their product by the American Association of State Highway and Transportation Officials. Footing and underslab drains are all available in HDPE.

5) Obstacles to Change

Journal articles and reports have some consensus as to why PVC has made such strong inroads in the water and sewer markets, and why HDPE, a viable alternative resin, has had difficulty in the market place. Primarily it has to do with what was there first, and a resistance to change.

According to an Environment Canada report, "In the case of HDPE, one reason for the low market share is the different marketing strategies initially employed for PVC and HDPE. Though HDPE has always been a competing plastic, with a longer history of use in pipe than PVC, the initial target markets for HDPE pipe suppliers were industrial settings, such as the chemical process industries, and the mining sector. In contrast, PVC pipe suppliers, who also sold ductile iron pipe, targeted municipal infrastructure pipe markets. As a result, municipal design engineers and contractors are more familiar working with PVC pipe, and seldom specify or design HDPE systems." (Env. Canada)

A trade journal article reporting on the difficulty in breaking into the market reports, "Even though polyethylene pipe has gained AWWA acceptance, U.S. water utilities and the engineers who design water systems have been slow to consider it as an alternative to the products they know and have used for years. Why risk trying something that – to the potable water industry- is new? (Underground Construction, June 2000).

One of the great barriers to changing the PVC water and sewer market is the resistance to change. Most engineers, contractors and public works officials have been working with the same materials for a long time, have become very familiar with their characteristics and are not anxious to take on a new material with different characteristics.

Appendix A – PVC Consumption Breakdowns

PVC Pipe Market

The figure below categorizes PVC consumption and demonstrates that construction consumes over three quarters of the PVC in the US and hence is the most significant end use of PVC (Figure 1).
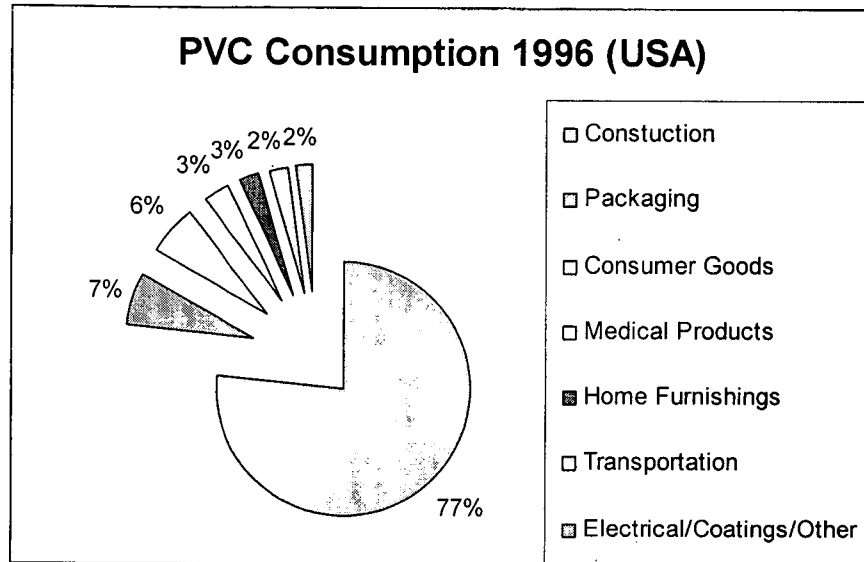

PVC Consumption 1996 (USA)

- □ Constuction
- □ Packaging
- □ Consumer Goods
- □ Medical Products
- ▣ Home Furnishings
- □ Transportation
- ▣ Electrical/Coatings/Other

3% 3% 2% 2%
6%
7%
77%

Figure 1.

Figure 2 depicts a sub-sector breakdown of PVC use in the construction sector and shows that the most significant segment is Pipes, tubing and fittings consuming about 2/3 of the total (Figure 2).

1996 PVC Consumption in Construction (USA)

- □ Pipe Tubingand Fittings
- ▣ Siding
- □ Windows and Doors
- □ Flooring
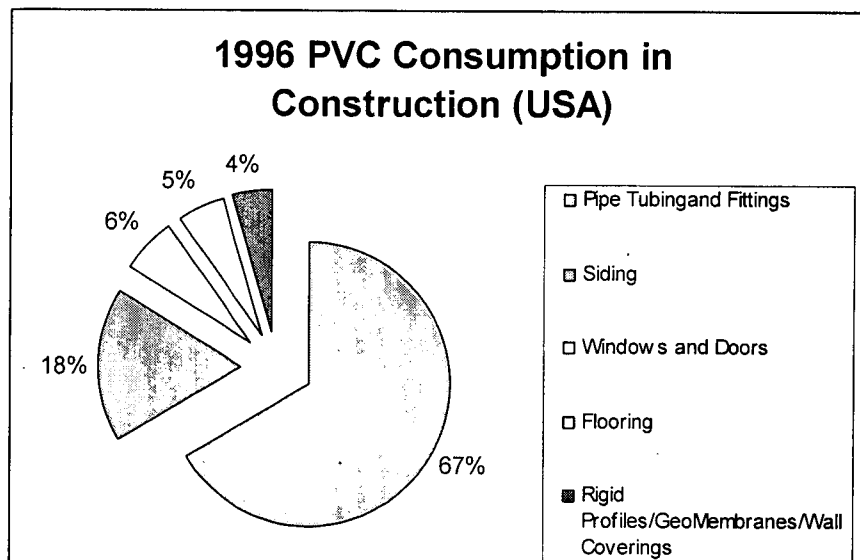- ▣ Rigid Profiles/GeoMembranes/Wall Coverings

5% 4%
6%
18%
67%

Figure 2.

Breaking out Pipes, tubes and fittings from other construction uses we see that this sub sector represents almost half of the entire PVC consumption (figure 3)
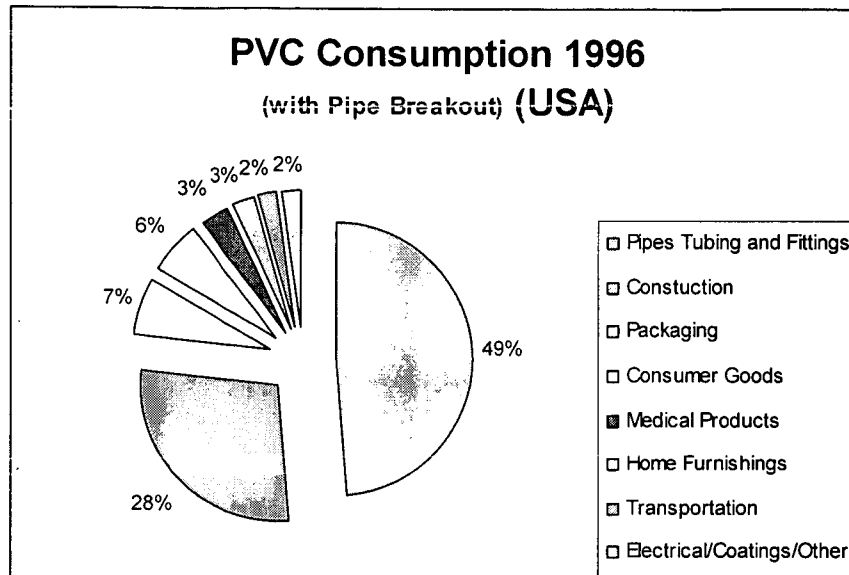

Figure 3.

The data suggests that even a small movement away from PVC pipes can significantly impact the size of the PVC market. Currently, for every 10% shift in the PVC pipe tubing fitting market, there is a corresponding 5% shift in the entire PVC market. Importantly, this does not necessarily mean other PVC sector targets should be abandoned. For example, market movement away from PVC medical devices, though smaller PVC use sector (3% of entire PVC consumption), may actually be a significant driver of the PVC pipe market, or other market sectors.

Appendix B - Sewer and Water Pipe Design Primer

The following primer is intended to provide the layperson with an introduction to pipe design, construction techniques, and associated vocabulary.

1) Engineering and Design

Water and Sewer Layout

Though it may not be obvious, pipelines are designed to follow the natural topographic variation and mimic natural drainage flow to take advantage of gravity. It is important that pipelines not be too deep to make excavation and installation prohibitively expensive, but also that the pipeline not be so shallow that it is difficult to service the building.

Pressure Pipe

In pipes, fluids are transported under two conditions; pressure or gravity flow. These two methods are important as they have implications on pipe material selection and layout. In pressure pipe, fluids are moved through the pipe by a pump, and as a result are put under pressure. Water pipes are usually pressure systems, as lakes, rivers, reservoirs, and other bodies from where water is obtained are typically located at elevations below where the water needs to be delivered. Because water does not flow against gravity, water delivery to apartment buildings, and upper floors of houses needs to be pumped, and hence is under pressure. Because the fluid is under pressure, joints for pressure systems must be rather "strong" or tight, otherwise as the pressure wave hits the joint, the pipe will fall apart, or create unacceptable leaks. Most codes for pressure pipe have what is called an allowable leakage rate. This means that the code allows for pipes to have a small degree of leakage. Pipes which are seamless, such as HDPE will have no leakage, even though it may be allowed by code. Though wastewater is typically designed for gravity flow, there are occasions where wastewater is also pumped. Usually this occurs where the topography is very flat, or where there is a hill along the pipe route.

Gravity Pipe

As implied, gravity flow uses gravity to transport the liquid. Wastewater is typically conveyed in a gravity system. A major concern with gravity systems is what is called Inflow and Infiltration (I & I) where water enters cracks or leaky joints. This is a concern for a variety of reasons. First, it can cause added expense to the wastewater plant because the plant is "forced" to treat excess water that does not require treatment. Associated with this excess dilute loading is poor wastewater treatment and unneeded treatment expense. Secondly, it can cause overflows at the wastewater plant or in the downstream conveyance system during rainstorms when pipe capacity is exceeded. This is one reason why during heavy rains wastewater plants may not function and that there are overflows. It is not necessarily because of poor system design but because breakdown of old pipe or poor construction have allowed for I&I. When a pipe collection system passes through an area of high water table, outside I&I can be problematic. The water table puts pressure on the gravity pipe, and it is continuously forced into the collection system. A US standard for sewage water infiltration allowance is 200 gallons per inch diameter per mile per day.

Corrosion

In metal water pipes, corrosion can occur because chemical reactions cause the pipe to act mildly electrically charged. This charge can cause it to release ions, causing it to lose strength. This can be remedied typically by supplying coatings such as tar or enamel.

In sewer pipes corrosion can occur because of chemical reactions caused by the biological production of sulfuric acid. In concrete pipes, the acid reacts with the lime to form calcium sulfate which lacks structural strength. The best protection is corrosion resistant pipe such as vitrified clay or plastic. Concrete pipe can be protected with coatings and or linings.

Flexible Pipe

Pipes with higher flexibility, such as PVC and HDPE (and larger diameter ductile iron) require proper pipe bedding and full sidefill support to resist deflection. The bedding, the sidefill and the walls of these "flexible" pipes must form a structural unit to resist the pipe deflection caused by overlying soil loads. In practice, this means that these pipes require increased labour and materials for backfilling and sidefilling.

Joints

There are a variety of ways in which pipes are joined. These are:

- **Mechanical** – a joint where pipes are joined by bolting or threaded their ends together.

- **Solvent Cement** –Solvents are used to join PVC DWV pipe. The solvent is used to soften and "glue" two pipe sections together. Health concerns have been raised about these solvents.

- **Welded** – both metal and some plastic pipes can be welded. Plastic pipe uses a hot plate to melt the ends of the plates to be joined. The plate is removed and the ends are pushed together using joining machinery, creating a seamless joint.

- **Bell and Spigot** – Bell and spigot joints are often used in gravity lines. With bell and spigot joints, each pipe length has a bell (or larger diameter end piece) end and spigot (or normal diameter) end. The spigot is inserted into the bell via a compression fit. Much sewer work uses bell and spigot joints.
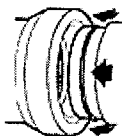
Bell and Spigot Joint
best fit gasket company   http://www.bestfitt.com/instructions/prepjoin.htm

2) Construction

Traffic

Traffic can add significant changes to pipeline project. In a new subdivision, the entire pipeline length can be excavated and the pipe placed without disturbing circulation. In an urbanized area, because of traffic flow and associated safety concerns, it can be almost impossible to dig up an entire street to lay pipe. When pipe is place in urbanized areas, the street is typically dug up section by section. A section of pipe is laid,

the hole backfilled, the adjacent section of street excavated, the new piece of pipe joined, and the hole backfilled. In this way, the excavation site "moves" along the route of the new pipeline with little disruption of street level traffic. This type of construction requires the joining of pipe sections to form one contiguous pipeline versus the placement of one long section of pipe. One disadvantage to this form of pipeline placement are that there are many joints each with the potential for failure or leakage The advantage is that there is little disruption to above grade activities. Trenchless technologies which favor HDPE pipe are now becoming commonplace.

Trenchless Technologies

i) Sliplining

If an older pipe is to be replaced, sliplining is frequently used to minimize installation costs. Costs are minimized because no excavation is required. Sliplining involves the placement of newer pipe inside that of an older, usually failed pipe. As the inside diameter of the "new' pipe will be smaller than the old, the new smaller pipe diameter will be able to carry less flow so this method requires that there be excess capacity in the older larger pipe. The new pipe, in lengths of 1000m can either be pushed of pulled through the older pipe. (PM Construction)

ii) Pipe Bursting
This is a relatively new technique for pipe placement. It is the only trenchless technology that allows for the replacement pipe to have larger diameter than the original pipe. In this method, a pneumatic bursting machine is dragged through the existing pipe. Old pipe fragments are displaced into the surrounding soil and the new larger pipe, in lengths up to 500 meters, is pulled in behind as replacement.
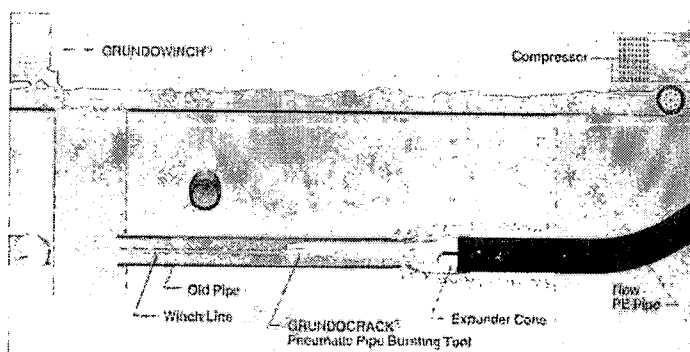
Appendix C - Case Studies

The following case studies have been provided to show examples of where and how PVC alternatives are used. All these case studies illustrate the use of HDPE, not because it is the preferred alternative to PVC, but because the other alternatives (ductile iron, copper, concrete) have already proven themselves in the North American marketplace.

Western Lake Superior Sanitary District commits to PVC free pipe The Western Lake Superior Sanitary District (WSLLD) is a regional wastewater treatment plant located in Duluth, Minnesota. It is the largest American point source discharge to Lake Superior. The WLSSD, has adopted a nationally recognized pollution prevention program which has as its basis a commitment to zero discharge of persistent toxic substances. This commitment reads:

> "The WLSSD as a discharger to Lake Superior is committed to the goal of zero discharge of persistent toxic substances and will establish programs to make continuous progress toward that goal. The District recognizes step-wise progress is only possible when pollution prevention strategies are adopted and rigorously pursued. These approaches will focus upon our discharge as well as indirect sources. WLSSD will work with its users to implement programs, practices, and policies which will support the goal.... WLSSD recognizes that airborne and other indirect sources beyond District control must be addressed in order for significant reductions to occur."

One component of their P2 program is a PVC free policy as a means towards dioxin reduction. As a wastewater treatment plant this policy has been applied to assist in the purchase of PVC-free pipe, an alternative PVC-free liner for their new anaerobic digestion facility, preference for PVC alternatives in their master plan development, PVC free electrical applications, and in the elimination of other uses of PVC such as office products. www.wlssd.duluth.mn.us

Bow, NH uses HDPE for roadway drainage. The community of 6,500 residents has 110 miles of roadway, and as old roads are upgraded and new roads built, the town includes storm drains made of HDPE. The corrugated polyethylene pipe was chosen for its ability to withstand frost action in the varied soil conditions beneath the town. "Metal pipe and cement pull apart from heat, and the freeze-and-contract movement in the winter. If there's a pocket of clay, water beneath the surface humps it up when it freezes, and that makes metal pipe come apart at the joints," comments Cleverly, the city engineer, noting that he hasn't seen any similar problems with corrugated polyethylene pipe. Additionally, Cleverly likes the safety factor HDPE pipe provides over metal pipe. He describes freshly-cut metal pipe ends as, "razor-sharp," compared to HDPE. "We try to be as safety-conscious as possible," he says. (CPPA website)

Atlanta Parks & Recreation uses 4" and 6" perforated polyethylene pipe to improve the hydraulic performance of a series of French drains running through the park and alongside a ball field. The Artis Group, Decatur, Ga., installed 1,000 linear feet of perforated pipe down the center of the drains to speed water flow. The smooth interior of the pipe provided greater hydraulic efficiency than ditches alone. (CPPA website)

HDPE pipe chosen for municipal sewer lines in Missoula, MT. City engineers evaluated all types of pipe and chose Hancor corrugated polyethylene. (Hancor Inc. website)

Appendix D – PVC Alternative comparisons

Technical Comparison of PVC and Ductile Iron Pipe

Technical Characteristics	PVC	Ductile Iron
Material Properties		
Corrosion Resistance	Resistant to acids	Can corrode; requires protection in some acidic soils and septic waters
Chemical Resistance	Can soften/degrade with organic solvents at high concentrations	Resistant to organic solvents; requires protection from acids
Impact Resistance	Moderate	High
Hydrostatic strength	Moderate	High
Tensile Strength	Moderate	High
Pipe Stiffness	Flexible; bends moderately	Flexible; bends slightly
Installation Factors		
Handling, weight	Light (~15 kg/m - 8" DR 18)	Heavy (32-36 kg/m - 8" Class 350)
Joining	Push on joints most common; mechanical and butt-fusion joints possible	Push-on joints most common; accommodates some deflection; mechanical joints possible
Bedding	generally requires more sidefill support to control deflection	more rigid at lower diameters; still requires careful bedding
Service		
Durability	High	High (with corrosion control as required)
Joint Integrity	Long term reliability	Long term reliability
Water Flow	Smooth walls; low friction factor	Slightly higher friction factor; larger internal diameter; higher flow
Temperature Range	Lower impact resistance with decreasing temperatures; lower tensile strength with increasing temperatures	Handles very high and low temperatures

Source: Env. Canada

Technical Comparison of PVC and HDPE Pipe

Characteristic	PVC	HDPE
Durability	Decades	Decades
Joining	bell and spigot push-on	butt-fusion above ground mostly, bolted flange for equipment connections
Joint integrity	tight seals; low leakage	butt-fusion results in tight seals
Weight	more dense than HDPE	less dense than PVC
Ductility	more stiff than HDPE	less stiff then PVC
Flexibility	rigid	flexible
Pressure rating	more susceptible to surge, hammer shocks	less susceptible to surge, hammer shocks
Tensile strength	PVC has better strength to volume ratio	HDPE has less strength to volume ratio
Internal wall smoothness	close to HDPE	close to PVC
Abrasion resistance	moderate	high
Chemical resistance	moderate	very good
Impact resistance	brittle at very low temperature, glass transition temperature higher than HDPE	better low temperature resistance, glass transition temperature lower than PVC
Fire resistance	will not sustain combustion	will sustain combustion
Tapping	mechanical taps	fusion or mechanical tapping

Env. Canada

Technical Comparison of PVC and Concrete Sewer Pipe

Technical Characteristics	PVC	Concrete
Material Properties		
Corrosion Resistance	Resistant	resistant
Chemical Resistance	susceptible to some hydrocarbon solvents	susceptible to acids (i.e. sulphuric acid); solvents may cause dissolution
Impact Resistance	moderate; reduced at very low temperatures	moderate
Abrasion Resistance	High	high; moderate under acidic conditions
Tensile Strength	moderate; flexible	high; rigid sections; flexibility in system due to shorter lengths
Soil Stress Resistance	flexible; withstands stress with sidefill support	withstands high soil loads
Installation Factors		
Handling, weight	light (13 kg/m); long (6.1m) sections (8" basis)	heavy (72 kg/m); short (1.2 m) sections (8" basis)
Joining	push on joint	push-on joint; more joints
Bedding	180° bed tamping required	lower half support may be necessary
Service		
Durability	high; long life span expected, not proven beyond 30 years	high; long lifespan
Joint Integrity	long-term reliability with proper installation	long-term reliability with proper installation
Water Flow	smooth walls; low friction	smooth walls; low friction
Temperature Range	lower impact resistance with decreasing temperatures; flexibility increases with increasing temperatures	wide range application

Env. Canada

Technical Comparison of PVC and HDPE Sewer Pipe

Characteristic	PVC	HDPE
Durability	decades	decades
Joining	bell and spigot push-on	bell and spigot push-on, butt-fusion, clam shell connections
Joint integrity	tight seals; low infiltration	tight seals; low infiltration (higher for clam shell enclosures)
Weight	more dense than HDPE	less dense than PVC
Ductility	less ductile than HDPE	more ductile than PVC
Flexibility	flexible	flexible
Tensile strength	better strength/volume ratio	lower strength to volume ratio
Internal wall smoothness	close to HDPE	close to PVC
Abrasion resistance	moderate	high
Chemical resistance	softens with solvents at high concentrations	very good
Impact resistance	decreases at very low temps., glass transition temp. higher than HDPE	better low temp. resistance, glass transition temp. lower than PVC
Fire resistance	resistant to combustion	will sustain combustion

Env. Canada

Water and Sewer Pipe Market Share, 1993
(% of length) (what about <4"?)

Type of Pipe	Water main		Sanitary and Sewer Pipe		
	4"-12" (Small)	14"-36" (Large)	4"-15" (Small)	18"-36" (Medium)	36"+ (Large)
PVC	88%	25%	85%	34%	0%
HDPE	0%	10%	5%	2%	0%
Ductile iron	12%	35%	0%	0%	15%
Concrete	0%	30%	10%	64%	85%
Total	100%	100%	100%	100%	100%

Table 2. Environment Canada

APPENDIX E: Manufacturers and suppliers of HDPE piping

Agents Private International (HDPE duct and conduit)
Richmond Hill, Ontario, Canada
416-281-6902
http://www.agtprint.com

Arnco (HDPE conduit and duct)
Elyria, OH
800-321-7914
www.arncocorp.com

Chevron Phillips Chemical Company LP (HDPE pipe & conduit)
The Woodlands, TX
(800) 231-1212
http://www.cpchem.com

Endot Industries, Inc. (HDPE pipe and conduit)
Rockaway, NJ
1-800-44-ENDOT(443-6368)
http://www.endot.com/market/

Hancor (recycled HDPE drainage drain)
Findley, OH
1-888-FOR PIPE
www.hancor.com

ISCO Industries, LLC (HDPE pipe)
Louisville, KY
1-800-345-ISCO
www.isco-pipe.com

Lamson & Sessions (HDPE conduit)
Cleveland, Ohio
Phone: (800) 321-1970
http://www.lamson-sessions.com/news_hdpeconduit.htm

Vanguard Piping Systems (HDPE and PEX piping)
McPherson, Kansas
1-800-775-5039
www.vanguardpipe.com

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Dioxin, PVC, and Health Care Institutions

What is dioxin?

Dioxin is the name given to a group of persistent, very toxic chemicals. The group includes chlorinated dibenzo-furans, and dibenzo-dioxins, the most toxic of which is 2,3,7,8 -tetra-chlorodibenzo-p-dioxin (TCDD). The group also includes related compounds which are structurally similar and are dioxin-like in their activity. The toxicity of these compounds is measured against TCDD using "toxic equivalents," which assign a fractional potency to each dioxin. Dioxins, defined here as dioxins and furans, have equivalence factors assigned to them. The US Environmental Protection Agency (EPA) has not assigned equivalence factors for brominated dioxins, brominated furans, brominated biphenyls and polychlorinated biphenyls (PCBs), although it is believed each group includes some dioxin-like compounds.

Dioxins and related compounds are highly persistent in the environment and in living organisms. They are bioaccumulative and fat-soluble. Their concentrations increase as they biomagnify up the food chain.

What are the hazards of dioxin?

Dioxins are extremely toxic and potent environmental contaminants. They modulate and disrupt growth factors, hormones, enzymes, and developmental processes. In animals, dioxin causes cancer in multiple organ systems, sometimes at exposure levels as low as nanograms per kilogram of body weight. Prenatal exposure to dioxin in rodents substantially increases the risk of breast cancer later in life.[1] Human epidemiological studies conclude that dioxin causes cancer in humans as well.[2] A draft report by the EPA estimates that as many as one in 1,000 of the most highly exposed people in the general population are at risk of developing cancer because of dioxin.

Dioxin also has widespread effects on reproduction and development, as shown in animal and human studies. Tiny doses in the range of nanograms (one thousandth of one millionth of a gram) to micrograms (one millionth of a gram) per kilogram of body weight of dioxin can cause harm. Exposure to these levels on a single day during pregnancy cause permanent disruption of male sexual development in rodents, including delayed testicular descent, lower sperm counts, and feminized sexual behavior.[3] In primates, small dietary exposures to dioxin are associated with an increased risk and severity of endometriosis.[4] A study in humans also shows higher levels of dioxin in women with endometriosis than in a control population.[5]

Dioxin is particularly toxic to the developing immune system. Animal tests show that nanograms per kilogram doses given 1-4 times during pregnancy cause permanent alterations in the immune system of offspring.[6] Human studies also show an increased susceptibility to infection and changes in immune system parameters as a result of in utero exposure to ambient environmental levels of dioxin and dioxin-like compounds.[7,8] Low levels of exposure during pregnancy also alter thyroid hormone levels in mothers and offspring, perhaps explaining neurological effects, including learning disabilities, that are seen in carefully conducted primate studies.[9]

How are we exposed?

The US EPA estimates that over 90% of our exposure is through food, with major sources including beef, dairy products, fish, pork, and breast milk. Dermal, oral and inhalation routes of exposures can also be important for people living near dioxin sources.

What is the level of exposure in the general population?

The general population, through ordinary dietary exposures, carries a current body burden of dioxin that is near or above the levels that cause adverse effects in animal tests. Through food alone, Americans are getting 22 times the maximum daily dioxin exposure considered by the US EPA to be without adverse effects.

Breast milk contamination is such that the nursing infant, during vulnerable periods of development, is exposed to dietary levels of dioxin 35 to 65 times the amount considered safe. Nonetheless, breast feeding remains far superior to formula feeding for a variety of reasons, and reducing breast feeding is not an appropriate public health response.

What are the sources of dioxins?

Dioxins are unintentionally formed during a variety of industrial processes that include chlorinated substances. Dioxin-like compounds can be generated and released to the environment from various combustion processes when chlorine donor compounds are present. Chlorine donor compounds can include polyvinyl chloride (PVC) plastic and other chlorinated compounds. Dioxin compounds can also be formed during the manufacture of chlorinated materials like PVC, chlorinated solvents and pesticides. Dioxins can also be formed during the bleaching of paper with chlorine, and in other industrial and combustion processes that include the presence of chlorine.

The primary source of dioxins from the health care sector has historically been waste incineration. Chlorine-containing products burned in incinerators, including medical devices and products, provide the chlorine necessary for dioxin formation.

New federal rules have resulted in the closing of most medical waste incinerators. In addition, large incinerators that will continue to operate must meet stricter emission limits. Those rules will eventually reduce the health care sector's contribution to dioxin levels in the environment. Although the contribution of dioxin from incinerators is declining, dioxin sources related to health care remain. The production of materials to create chlorinated health care products, like PVC IV bags and gloves, can result in dioxin formation. In addition, chlorinated health care waste that is burned in backyard burn barrels, or catches fire once taken to the landfill, has the potential to create and disperse dioxin. Once dioxin is emitted into the air from incinerators and other sources, rain, snow and dust can carry it to the surface of the earth, where it can enter the food chain.

What is the evidence that the manufacture of PVC feedstocks is linked to dioxin formation?

The draft dioxin reassessment recently released by the EPA reviews the contribution of PVC manufacturing to dioxin emissions.[10] According to calculations of the Vinyl Institute (an industry trade association), reviewed and given a medium confidence rating by the EPA,[11] the production of PVC and its feedstocks result in air releases of 11.2-31.0 grams toxic equivalency (TEQ)[12] dioxins and furans per year. These levels may understate the contribution of dioxin from the manufacture of PVC throughout its life cycle, both because there may be dioxin releases to land and water during the production phase, and because dioxin may be formed during disposal of the end product.

Under what conditions can the combustion of PVC result in dioxin formation?

The draft EPA dioxin reassessment also reviews the contribution of waste incineration to dioxin emissions. The report summarizes a large body of literature that finds carbon and catalysts must be present in an incinerator in order for dioxins to form.[13] PVC is usually the largest chlorine source in municipal and medical waste incinerators. The relationship between chlorine inputs into an incinerator and dioxin formation, however, depends upon combustion conditions.

For uncontrolled combustion, such as open burning of household waste, landfill fires, or building fires, a direct association between chlorine content of the combusted material and dioxin formation has been established. For example, a study of the open burning of household waste showed that waste containing larger amounts of PVC (4.5% vs. 0.2%) produced substantially larger amounts of dioxins in air emissions (269 vs. 44.3 microgram/kg waste burned) and ash (7,356 vs. 489 microgram/kg waste burned).[14]

In modern, commercial waste incinerators, the rate at which dioxins are formed and released depends upon chlorine inputs, incinerator design, operating conditions, the presence of catalysts, and pollution control equipment. While the EPA concludes, based on studies of modern waste incinerators, that the largest determinants of dioxin formation are operating conditions (including overall combustion efficiency, post-combustion flue gas temperatures, and residence times — and the presence of iron or copper catalysts) rather than chlorine content alone, there is little doubt that chlorine content of the waste feed is critical.

Several laboratory and incinerator pilot studies have found a direct relationship between chlorine loading and dioxin emissions.[15] In addition, the EPA's conclusion appears to rest largely on an analysis of incinerator emissions data by Rigo, et al. (1995), which has serious methodological flaws.[16] It is also important to note that the EPA conclusion refers only to stack gas emissions, which are a relatively small fraction of total dioxins released from incinerators, and does not consider releases in fly ash, bottom ash, and water discharges.

For any given waste incinerator, according to the EPA, conditions may exist in which changes in chlorine content of waste feed will correlate highly with dioxin and furan emissions. These conditions may prevail during start-up or shut-down, changes in waste feed rate, or operational upsets. Although modern commercial waste incinerators are designed and intended to be operated to minimize release of dioxins and other hazardous air pollutants, they are, nevertheless, an important source of dioxin releases.

What is Health Care Without Harm's position on dioxin, PVC, and medical waste incineration?

Available data reveal a complex relationship among chlorine feed, design and operating conditions, and dioxin emissions. It is certain that chlorine sources are necessary for dioxin emissions, and PVC products are a large chlorine source. It is also certain that combustion, even in well controlled incinerators, will release dioxins in stack gases, fly ash, bottom ash, and water discharges. Moreover, even modern, well-designed incinerators do not consistently operate at optimal combustion conditions. Further, not all burning of chlorinated products occurs in controlled conditions, and uncontrolled burning can result in large dioxin releases.

For these reasons, along with concern about other hazardous pollutants emitted from waste incinerators — including mercury, particulates, sulfur and nitrous oxides, and hydrochloric acid — Health Care Without Harm has taken the pollution prevention position that PVC use should be minimized and ultimately eliminated, alternatives should be used when available without compromising patient safety or care, and all unnecessary waste incineration should be avoided.

Notes

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10. See US EPA, Report #: EPA/600/P-00/001Ab, March 2000

11. The EPA developed a three-part confidence rating scheme: "high" means the estimate is derived from a comprehensive survey; "medium" is based on estimates of average activity and number of facilities or a limited survey; and "low" is based on data judged possibly non-representative

12. Since the toxicity of the various congeners of dioxins and furans varies, the toxicity of a given mixture of congeners is usually expressed as TEQs, where the most toxic form is assigned a value of one and the relative contribution of others is calculated accordingly.

13. Dioxins/furans form most readily in commercial incinerators as the combustion gases reach cooler temperatures, primarily in the range 200-450°C.

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15. For example, see: Bruce, et al, The role of gas phase Cl2 in the formation of PCDD/PCDF during waste combustion, Waste Management, 11: 97-102, 1991; Kanters, et al, Chlorine input and chlorophenol emission in the lab-scale combustion of municipal solid waste, Environmental Science and Technology, 30: 2121-2126, 1996; and Wagner and Green, Correlation of chlorinated organic compound emissions from incineration with chlorinated organic input, Chemosphere, 26: 2039-2054, 1993.

16. In 1995, the Vinyl Institute commissioned a report, prepared for the American Society of Mechanical Engineers, that purported to examine the relationship between PVC in incinerator waste feed and dioxin emissions (Rigo HG, Chandler JA, Lanier WS, *The relationship between chlorine in waste streams and dioxin emissions from combustors*, The American Society of Mechanical Engineers, 1995). After examining data from dozens of burns in a number of municipal and medical waste incinerators, the report concludes that there is no statistically significant relationship between fuel chlorine content and dioxin emissions. The analysis, however, is flawed in a number of significant ways. First, there was no attempt to control for differences in incinerator design or operating conditions so that the question of interest could be addressed independent of other variables. Second, the authors used data collected for regulatory compliance purposes and not intended to examine the relationship between chlorine input and dioxin output. Without actually knowing the PVC content of the waste feed, they were forced to use hydrochloric acid emissions as a surrogate for chlorine loading. Hydrochloric acid emissions can be used to approximate chlorine loading but do not provide precise estimates. Moreover, in the tested incinerators, dioxin concentrations were sampled at various points in the exhaust stream – from boiler outlet to further downstream – predictably a source of variability, since dioxin can be formed at various points in the exhaust, depending on temperature and fly ash composition. This sampling strategy provides a poor estimate of total dioxin emissions to the air and ash. In summary, this analysis relies on data that are poorly suited to answer the question of interest. A more complete referenced discussion of the connection between PVC incineration and dioxin formation may be found in: Thornton J., *Pandora's Poison: Chlorine, Health, and a New Environmental Strategy* (Chapter 7), MIT Press: Cambridge MA, 2000.

The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case–Control Study

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Global phthalate ester production has increased from very low levels at the end of World War II to approximately 3.5 million metric tons/year. The aim of the present study was to investigate potential associations between persistent allergic symptoms in children, which have increased markedly in developed countries over the past three decades, and the concentration of phthalates in dust collected from their homes. This investigation is a case–control study nested within a cohort of 10,852 children. From the cohort, we selected 198 cases with persistent allergic symptoms and 202 controls without allergic symptoms. A clinical and a technical team investigated each child and her or his environment. We found higher median concentrations of butyl benzyl phthalate (BBzP) in dust among cases than among controls (0.15 vs. 0.12 mg/g dust). Analyzing the case group by symptoms showed that BBzP was associated with rhinitis ($p = 0.001$) and eczema ($p = 0.001$), whereas di(2-ethylhexyl) phthalate (DEHP) was associated with asthma ($p = 0.022$). Furthermore, dose–response relationships for these associations are supported by trend analyses. This study shows that phthalates, within the range of what is normally found in indoor environments, are associated with allergic symptoms in children. We believe that the different associations of symptoms for the three major phthalates—BBzP, DEHP, and di-*n*-butyl phthalate—can be explained by a combination of chemical physical properties and toxicologic potential. Given the phthalate exposures of children worldwide, the results from this study of Swedish children have global implications. *Key words:* allergy, asthma, BBzP, children, DEHP, homes, phthalates. *Environ Health Perspect* 112:1393–1397 (2004). doi:10.1289/ehp.7187 available via http://dx.doi.org/ [Online 15 July 2004]

Airborne phthalate esters are present at detectable levels across the surface of Earth. They were first identified in outdoor urban air (Cautreels and Van Cauwenberghe 1976a, 1976b) and subsequently have been recognized as global pollutants (Atlas and Giam 1981; Giam et al. 1978) and major constituents of indoor air (Weschler 1980, 1984). Their presence in outdoor and indoor environments reflects their large emission rates coupled with moderate atmospheric lifetimes. The total global consumption of phthalate esters is estimated to exceed 3.5 million metric tons/year, with di(2-ethylhexyl) phthalate (DEHP) constituting roughly 50% of the market share (Cadogan and Howick 1996). Consumption of di-*n*-butyl phthalate (DnBP) and *n*-butyl benzyl (BBzP) phthalate is smaller but still quite large (> 100,000 metric tons/year each) (Cadogan and Howick 1996). Although DEHP plasticizes numerous products, roughly 95% of the current production is used in polyvinyl chloride (PVC) (National Toxicology Program 2003), where it typically constitutes 30% of PVC by weight (Cadogan and Howick 1996; Kavlock et al. 2002b). DnBP is used in latex adhesives, in nail polish and other cosmetic products, as a plasticizer in cellulose plastics, as a solvent for certain dyes, and, to a lesser extent than DEHP, as a plasticizer in PVC (Kavlock et al. 2002c). BBzP is a plasticizer for vinyl tile, carpet tiles, and artificial leather and is also used in certain adhesives (Kavlock et al. 2002a).

Research groups have assessed the exposures of various populations to phthalate esters by using their metabolites in human urine as biomarkers [Barr et al. 2003; Blount et al. 2000; Centers for Disease Control and Prevention (CDC) 2003; Koch et al. 2003]. The biomarker results translate to daily exposures for DnBP, BBzP, and DEHP of 1.5, 0.88, and 0.71 µg/kg/day in the United States (Kohn et al. 2000); 0.95, 0.71, and 0.84 µg/kg/day in the United States (derived from data from Barr et al. 2003, their Table 1, using the procedure outlined by Kohn et al. 2000); and 5.22, 0.60, and 13.8 µg/kg/day in Germany (Koch et al. 2003). These findings confirm the relatively large daily exposure to phthalates in industrialized countries. Although the dominant route of exposure to DnBP, BBzP, and DEHP is thought to be via ingestion (Fromme et al. 2004; Kavlock et al. 2002a, 2002b, 2002c), few if any population-based data are available to support this statement. Indeed, a recent study has demonstrated associations between phthalate concentrations in inhaled air and urinary monoester metabolites (Adibi et al. 2003).

The incidence of asthma and allergy has increased throughout the developed world over the past 30 years (Beasley et al. 2003).

The short interval over which it has occurred implies that the increase is caused by changes in environmental exposures rather than genetic changes (Etzel 2003; Strachan 2000). Changes in indoor environments warrant special attention because indoor air constitutes a dominant exposure route. Increased exposures to allergens and/or adjuvants (enhancing factors) may each be partially responsible for the increase. Multidisciplinary reviews of the scientific literature on associations between indoor exposures and asthma and allergies (Ahlbom et al. 1998; Andersson et al. 1997; Bornehag et al. 2001; Schneider et al. 2003; Wargocki et al. 2002) indicate that the underlying causal factors responsible for these increases remain unknown.

The use of plasticized products and, consequently, exposures to phthalate esters have increased dramatically since the end of World War II. Phthalate esters have been suggested to act as either allergens or adjuvants (Jaakkola et al. 1999; Oie et al. 1997). Several recent studies have examined the ability of different phthalate esters to function as adjuvants in BALB/c mice injected with a known antigen. DEHP displayed an adjuvant effect with immunoglobulin G1 at a concentration of 2,000 mg/mL after both one and two boosters (Larsen et al. 2001b). In contrast, DnBP only showed an adjuvant effect with immunoglobulin G1 after the second booster (Larsen et al. 2002), and BBzP showed no adjuvant effect (Larsen et al. 2003). Consistent with these results, the monoester of DEHP showed an adjuvant effect whereas the monoesters of DnBP and BBzP did not (Larsen et al. 2001a).

The present study is a nested case–control study on 198 symptomatic children and 202 healthy controls, including detailed clinical examinations by physicians in parallel

with extensive inspections and measurements within the subjects' homes. The cases and controls were selected from the first phase (Dampness In Buildings and Health, phase I), which was a cross-sectional questionnaire soliciting health and environmental information regarding all 14,077 children 1–6 years of age in the county of Värmland, Sweden; responses were obtained for 10,852 (Bornehag et al. 2003).

The aim of the present study was to investigate potential associations between persistent allergic symptoms in children and the concentrations of different phthalates in dust collected from their homes.

Materials and Methods

Inclusion criteria for cases and controls. The selection criteria for the cases (Dampness In Buildings and Health, phase II) were as follows: *a)* in the initial questionnaire, reports of at least two incidents of eczema, or wheezing or rhinitis without a cold, during the preceding 12 months; and *b)* in the follow-up questionnaire 1.5 years later, at least two of three possible symptoms reported. Inclusion criteria for the controls were *a)* no symptoms in the first questionnaire and *b)* no symptoms in the follow-up questionnaire. For both groups they had to *c)* not have rebuilt their homes because of moisture problems and *d)* not have changed residence since the first questionnaire. All children with at least two symptoms in the first questionnaire were invited to participate in the case–control study (*n* = 1,056, corresponding to 9.7% of the total population). In the first questionnaire, 5,303 (48.9%) reported no airway, eye, nose, or skin symptoms. Of these, 1,100 children were randomly selected and invited to participate in the case–control study. This process ultimately yielded 198 cases and 202 controls.

Families were more inclined to participate if the child was reported to have more symptoms, if there was no smoking in the family, and if they belonged to a higher socioeconomic group.

Medical examination. The medical examination of the 400 children (3–8 years of age) was performed during the same 2 weeks that the technical investigations of the homes, including dust collection, were carried out. Medical doctors examined the children and took a detailed history of each child. Blood samples were drawn from 387 children and screened for common allergens (Phadiatop, Pharmacia & Upjohn Diagnostics, Uppsala, Sweden), timothy, birch, mugworth, cat, horse, dog, house dust mites (*Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*), and one mold (*Cladosporium*).

Physicians' diagnoses of the children agreed well with the case–control status as reported in the questionnaire. All children with obvious

asthma were found among cases, whereas 10 cases were found among controls (two children with rhinitis and eight children with eczema). Furthermore, 13 cases were found to be misclassified. In the analyses regarding case–control status, the study design has been used; that is, the 23 (10 plus 13) misclassified children have not been reclassified.

Building investigations. There were 10 pairs of siblings among the 400 children; hence, they lived in 390 buildings. Between October 2001 and April 2002, six professional inspectors performed visual inspections and indoor air quality assessments, including dust sampling, in these 390 dwellings. During these investigations, a preestablished checklist was followed regarding building characteristics, mold and water damages, surface materials, and other building-related items.

Phthalates in dust. Samples of dust from 390 homes were collected from molding and shelves in the children's bedroom. The dust was collected on 90-mm membrane filters in holders made of styrene-acrylonitrile polymer mounted on a sampler made of polypropylene (VacuuMark disposable nozzle; Petersen Bach, Bjerringbro, Denmark) connected to a vacuum cleaner. The filter was weighed before and after sampling under controlled conditions. Conditioning the filters before weighing (23°C, 50% relative humidity) was critical to obtaining reproducible filter weights. From the 390 homes there were 9 missing samples, 13 samples with errors in the laboratory analysis, and 6 samples with a negative dust weight. Consequently, there were 362 valid samples. Only filters with a reliably measurable net increase in weight (≥ 25 mg) were included in the present analysis; 346 of the 362 dust samples met this criterion.

The dust samples were extracted in pre-cleaned 10-mL glass vials for 30 min using 2 mL dichloromethane. This procedure was repeated, and the two extracts were then combined and transferred to 3-mL autosampler vials. Aliquots from these vials were injected into either a gas chromatograph/mass selective detector (GC/MSD) for phthalate identification or a GC/flame ionization detector for quantitation. GC was performed using a 25-m capillary column (HP 1C; Agilent, Folsom, CA, USA; inner diameter, 0.2 mm; stationary phase, polydimethyl siloxane). The injector temperature was 280°C; column temperature started at 100°C for 3 min and then increased at 8°C/min to 300°C, which was maintained for 20 min. The detector temperature and transfer line to the MSD were maintained at 280°C. The analytical and field sampling techniques were tested in a preliminary study that found only limited influence from background contributions to the analyzed samples. In the present study, field blanks have indicated no significant background contributions.

The dust concentrations (milligram per gram dust) of six phthalates were determined: diethyl phthalate (DEP), diisobutyl phthalate (DIBP), DnBP, BBzP, DEHP, and diisononyl phthalate (DINP).

Statistical method. The concentrations of phthalates in the dust were log-normally distributed. Hence, analyses of potential associations between concentrations of phthalates in dust and health outcomes have been conducted using nonparametric tests (Mann-Whitney *U*-test). Log-transformed, normally distributed concentrations were tested with parametric tests (*t*-test). The concentrations are reported as medians, as arithmetic means, and as geometric means with 95% confidence intervals (CIs). The CIs were calculated with a back-transform of mean log ± 2 × SE. Dose–response relationships were tested by factoring the phthalate concentrations into quartiles and using both uni- and multivariate logistic regression analyses. Adjustments have been made for environmental tobacco smoke as well as sex and age of the child, because these have been associated with asthma and allergic symptoms. Adjustments for type of building were made, because living in a privately owned single-family house was a selection factor for both cases and controls (Bornehag et al., unpublished data). Indeed, cases and controls lived mainly in single-family houses (88.7%). Furthermore, the frequency of PVC as flooring material was lower in single-family houses than in multifamily houses (51.6 vs. 71.8%). Adjustments for the construction period of the building and self-reported water leakage in the home during the previous 3 years were made because these are associated with the concentrations of phthalates in dust. Finally, adjustments were made for exposure to other phthalates. Multiple logistic regressions were performed by a backward elimination technique where only significant variables were included in the final model. The analyses were considered statistically significant when *p* < 0.05.

The study was approved by the local ethics committee.

Results

Compared with other types of flooring materials, PVC flooring in the child's bedroom was positively associated with case status [adjusted odds ratio (OR), 1.59; 95% CI, 1.05–2.41].

Phthalates in dust. Results are presented in Tables 1–3 and Figure 1. In Tables 1 and 2, median phthalate dust concentrations are reported for data sets that include all valid samples with a reliably measurable net increase in weight (346 of 390 homes), and geometric mean concentrations are reported for data sets that exclude samples with phthalate dust concentrations less than the detection limit. (If, instead, nondetects were

assigned concentrations of one-half the detection limit, then for phthalates with a large number of nondetects, their dust concentrations would no longer be log-normally distributed.) The geometric mean concentrations of BBzP and DEHP were higher in bedrooms with PVC flooring than in bedrooms without such flooring [BBzP: 0.208 (n = 164) vs. 0.147 (n = 107) mg/g dust; DEHP: 0.994 (n = 186) vs. 0.638 (n = 155) mg/g dust; both p < 0.001 by t-test]. DEP, DIBP, DnBP, and DINP were not associated with PVC flooring.

Association between phthalates in dust and health effects. Cases had a higher concentrations of BBzP in the dust samples from the children's bedrooms than did the controls in parametric as well as in nonparametric tests (Table 1). Cases with physician-diagnosed rhinitis or eczema had higher BBzP concentrations in the bedroom dust compared with controls (Table 2). Furthermore, cases with doctor-diagnosed asthma had higher DEHP concentrations in the dust compared with controls. In analyses restricted to single-family and row houses, the same associations were found (data not shown).

In an analysis restricted to homes with PVC flooring in the child's bedroom (n = 189), the median BBzP concentration was significantly

higher among cases compared with controls (0.21 vs. 0.16 mg/g dust, respectively; Mann-Whitney U-test, p = 0.042), and BBzP was associated with rhinitis and eczema (Table 2). Such differences between cases and controls were not observed for DEHP.

BBzP concentrations in the highest quartile were associated with an increased risk of being a "case child" (Table 3). The same association was found after adjusting for possible confounders. Table 3 also shows associations between phthalates in dust and doctor-diagnosed asthma, rhinitis, or eczema. A dose–response relationship was found between concentrations of BBzP in dust and doctor-diagnosed rhinitis and eczema in both crude and adjusted analyses. For DEHP, a dose–response relationship was found for asthma in both crude and adjusted analyses, as well as in analysis restricted to single-family houses (data not shown for the latter).

Specific immunoglobulin E in blood. Figure 1 presents the concentration of phthalates in dust among cases and controls with and without specific immunoglobulin E in blood (i.e., atopics and nonatopics). Within the group of cases, the highest geometric mean concentrations of BBzP were found in dust from the bedrooms of atopics.

However, when comparing cases with and without atopy, the difference was not statistically significant (p = 0.564).

Discussion

In the present study we found associations between dust concentrations of specific phthalate esters and asthma, rhinitis, and eczema. As shown in Tables 2 and 3, BBzP is significantly associated with doctor-diagnosed rhinitis and eczema, whereas DEHP is significantly associated with doctor-diagnosed asthma. Interestingly, no such associations are found for DnBP despite the fact that the median concentrations of BBzP and DnBP in the settled dust were comparable (0.150 vs. 0.135 mg/g; Table 1). Hence, these three phthalates display strikingly different associations between their dust concentrations and the health outcomes monitored in this study. From a physical chemistry viewpoint, DnBP, BBzP, and DEHP are significantly different from one another; they possess different vapor pressures, polarities, water solubilities, and octanol/air partition coefficients. For example, the vapor pressures of DnBP and BBzP are two orders of magnitude greater than that of DEHP. This means that greater fractions of DnBP and BBzP are in the gas phase as

Table 1. Concentrations of phthalates in surface dust from children's bedrooms.

Phthalate	No. of homes[a]	Median (arithmetic mean) concentration of phthalates (mg/g dust)			U-test[c] (p-value)	No. of homes[d]	All samples GM conc	Cases			Controls		t-Test[e] (p-value)
		All samples (n = 346)	Cases (n = 175)[b]	Controls (n = 177)[b]				No.	GM conc [(95% CI) mg/g dust]		No.	GM conc [(95% CI) mg/g dust]	
DEP	346	0.000 (0.031)	0.000 (0.046)	0.000 (0.018)	0.628	47	0.073	22	0.102 (0.049–0.211)		26	0.058 (0.035–0.097)	0.200
DIBP	346	0.045 (0.097)	0.042 (0.102)	0.048 (0.092)	0.424	290	0.056	141	0.058 (0.048–0.070)		154	0.055 (0.046–0.065)	0.635
DnBP	346	0.150 (0.226)	0.150 (0.228)	0.149 (0.220)	0.914	308	0.174	158	0.171 (0.152–0.193)		154	0.178 (0.157–0.201)	0.639
BBzP	346	0.135 (0.319)	0.152 (0.472)	0.118 (0.163)	0.014	272	0.181	139	0.209 (0.180–0.244)		137	0.157 (0.139–0.178)	0.004
DEHP	346	0.770 (1.310)	0.828 (1.384)	0.723 (1.229)	0.160	343	0.789	173	0.836 (0.724–0.964)		176	0.741 (0.643–0.855)	0.232
DINP	346	0.041 (0.639)	0.000 (0.671)	0.047 (0.589)	0.848	175	0.451	87	0.453 (0.352–0.583)		90	0.446 (0.351–0.566)	0.925

Abbreviations: conc, concentration; GM, geometric mean.
[a]Number of homes with a dust sample weight > 25 mg. [b]The sum of cases and controls is 352 because, among the 346 bedrooms, there were six bedrooms shared by siblings. [c]Mann-Whitney U-test. [d]Number of homes with a dust sample weight > 25 mg and a phthalate concentration greater than the detection limit (0.040 mg/g dust for DnBP, BBzP, and DEHP). [e]Test of the difference between cases and controls made on mean log-transformed concentration.

Table 2. Concentration of phthalates (BBzP and DEHP) in surface dust for case children with a doctor-diagnosed disease compared with controls.

Phthalate	Disease	Cases[a]		Controls		U-test[b] (p-value)	Cases			Controls		t-Test[c] (p-value)
		No.	Median conc (mg/g dust)	No.	Median conc (mg/g dust)		No.	GM conc [(95% CI) mg/g dust]		No.	GM conc [(95% CI) mg/g dust]	
All homes												
BBzP	Asthma	106	0.152	177	0.118	0.064	82	0.219 (0.177–0.270)		137	0.157 (0.139–0.178)	0.005
	Rhinitis	79	0.181	177	0.118	0.007	65	0.237 (0.185–0.304)		137	0.157 (0.139–0.178)	0.001
	Eczema	115	0.181	177	0.118	0.001	95	0.224 (0.186–0.269)		137	0.157 (0.139–0.178)	0.001
DEHP	Asthma	106	0.899	177	0.723	0.008	106	0.966 (0.807–1.156)		176	0.741 (0.643–0.855)	0.022
	Rhinitis	79	0.783	177	0.723	0.383	78	0.811 (0.638–1.030)		176	0.741 (0.643–0.855)	0.510
	Eczema	115	0.844	177	0.723	0.111	115	0.855 (0.721–1.014)		176	0.741 (0.643–0.855)	0.207
Homes with PVC flooring in the child's bedroom												
BBzP	Asthma	59	0.195	82	0.159	0.168	52	0.237 (0.177–0.316)		71	0.177 (0.148–0.212)	0.076
	Rhinitis	45	0.216	82	0.159	0.008	43	0.265 (0.192–0.366)		71	0.177 (0.148–0.212)	0.018
	Eczema	70	0.216	82	0.159	0.003	66	0.257 (0.204–0.324)		71	0.177 (0.148–0.212)	0.011
DEHP	Asthma	59	1.006	82	0.855	0.149	59	1.148 (0.904–1.459)		82	0.938 (0.752–1.169)	0.228
	Rhinitis	45	0.792	82	0.855	0.924	44	1.040 (0.771–1.403)		82	0.938 (0.752–1.169)	0.586
	Eczema	70	0.904	82	0.855	0.379	70	1.045 (0.845–1.291)		82	0.938 (0.752–1.169)	0.491

Abbreviations: conc, concentration; GM, geometric mean.
[a]Cases with doctor diagnosed disease (asthma, rhinitis, or eczema). [b]Mann-Whitney U-test. [c]Test of the difference between cases and controls made on mean log-transformed concentration.

opposed to the condensed phase (i.e., associated with dust and airborne particles). We estimate that, for a particle concentration of 20 μg/m³, > 80% of airborne DnBP and > 80% of airborne BBzP are in the gas phase, whereas > 85% of airborne DEHP is associated with airborne particles (Weschler 2003). The deposition of a compound in the respiratory tract is strongly influenced by whether it is present in the gas phase or associated with airborne particles. Furthermore, as a consequence of their inherent chemical differences, DnBP, BBzP, and DEHP, as well as their monoester metabolites, produce different effects in a mouse model (Larsen et al. 2001a, 2001b, 2002, 2003). Furthermore, each of these phthalates has its distinct human metabolic pathway (Barr et al. 2003). We suspect that the different relative distributions between the gas and condensed phases, coupled with different toxicologic and pharmacokinetic behaviors, contribute to the fact that DnBP, BBzP, and DEHP are associated with different health outcomes (i.e., DnBP, no associations; BBzP, skin and mucosa symptoms; DEHP, lower airway symptoms).

In the present study there is a general association between PVC flooring and case status (OR, 1.59). Both BBzP and DEHP correlate with the amount of PVC flooring in the subjects' homes. However, these two phthalates are not associated with health effects simply because they are associated with PVC flooring.

This conclusion is supported by a number of observations: First, specific associations between BBzP and DEHP dust concentrations and doctor-diagnosed diseases (Table 3) are more pronounced than associations between PVC flooring and such diseases. Second, although BBzP and DEHP dust concentrations do correlate, the correlation is weak ($R = 0.52$), and they are associated with different health effects. Third, in a restricted analysis, including only homes with PVC flooring, higher concentrations of BBzP were found in dust from case homes than in that from control homes.

The reported concentrations of phthalates in the bedroom dust (Table 1) are consistent with those reported in other studies. In dust samples from 120 U.S. homes located on Cape Cod, Massachusetts (Rudel et al. 2003), the median concentrations were 0.34, 0.045, and 0.020 mg/g dust for DEHP, BBzP, and DnBP, respectively. In a study of 59 apartments in Berlin, Germany (Fromme et al. 2004), the median concentrations were 0.70, 0.030, and 0.047 mg/g dust for DEHP, BBzP, and DnBP. Clausen et al. (2003) measured mean DEHP concentrations of 3.2 mg/g dust in 15 Danish schools and 0.86 mg/g dust for 23 Danish homes. Oie et al. (1997) reported mean concentrations of 0.64 mg DEHP/g dust and 0.11 mg BBzP/g dust for 38 homes in Norway. Pohner et al. (1997) reported a 95th percentile DEHP concentration of 2.0 mg/g

dust for 272 German homes, whereas another German study on 286 homes reported a 95th percentile DEHP concentration of 2.6 mg/g dust (Butte et al. 2001).

Regarding atopic status and its association with phthalate dust concentrations, the chosen study design is not optimal. Because there were only 16 atopic controls, the power of the analysis on atopic children is limited. On the other hand, our findings could be interpreted to mean that the mechanism is of a nonimmunologic nature (e.g., exposure increases the risk for irritation).

To identify potential selection biases in the study group, we obtained information for all invited families from the first cross-sectional questionnaire. This revealed that the final study group contained significantly more single-family houses than the eligible population. Adjusting and restricting the analyses have addressed this problem. There was no selection bias regarding PVC flooring because included and nonincluded cases and controls reported about the same frequency of occurrence of PVC flooring in the child's bedroom (Bornehag et al., unpublished data). Furthermore, 10 controls and 13 cases were misclassified when comparing self-reported symptoms and doctors diagnoses. However, when these children were excluded from the analyses, the reported associations remained. Finally, to be included as a "case," a child was required to have at least two symptoms. Consequently, this study was not fine-tuned to examine associations between building factors and single symptoms (i.e., asthma, rhinitis, or eczema). However, even if the design is suboptimal, meaning it was more difficult to find associations between single symptoms and exposures, the association between selected building factors and single symptoms is meaningful and possibly underestimates true associations.

Table 3. Crude and adjusted ORs (95% CIs) between phthalates (BBzP and DEHP) in surface dust and case status or doctor-diagnosed disease.

Group[a]	1 (ref; n = 88)	2 (n = 88)	3 (n = 88)	4 (n = 88)	p-Value[b]
BBzP					
Ranges (mg BBzP/g dust)	0.00–0.05	0.05–0.13	0.13–0.25	0.25–45.55	
Crude analysis					
Case status	1.0	0.69 (0.38–1.26)	1.00 (0.55–1.81)	2.01 (1.10–3.69)	0.012
Asthma	1.0	0.63 (0.31–1.27)	0.59 (0.45–1.76)	1.92 (0.98–3.79)	0.039
Rhinitis	1.0	0.85 (0.38–1.89)	1.12 (0.51–2.47)	2.69 (1.26–5.76)	0.006
Eczema	1.0	0.74 (0.36–1.52)	1.44 (0.73–2.81)	2.52 (1.26–5.00)	0.002
Adjusted[c] analysis					
Case status	1.0	0.77 (0.40–1.46)	1.01 (0.53–1.90)	1.95 (1.02–3.74)	—
Asthma	1.0	0.67 (0.33–1.38)	0.88 (0.43–1.80)	1.87 (0.92–3.81)	—
Rhinitis	1.0	1.03 (0.44–2.39)	1.23 (0.53–2.88)	3.04 (1.34–6.89)	—
Eczema	1.0	0.84 (0.40–1.76)	1.45 (0.71–2.97)	2.56 (1.24–5.32)	—
DEHP					
Ranges (mg DEHP/g dust)	0.00–0.46	0.46–0.77	0.77–1.30	1.30–40.46	
Crude analysis					
Case status	1.0	0.91 (0.50–1.65)	1.05 (0.58–1.89)	1.44 (0.80–2.61)	0.199
Asthma	1.0	1.11 (0.53–2.31)	1.51 (0.74–3.07)	2.36 (1.17–4.75)	0.009
Rhinitis	1.0	1.12 (0.53–2.36)	0.96 (0.44–2.11)	1.55 (0.73–3.28)	0.331
Eczema	1.0	1.00 (0.50–1.97)	1.35 (0.70–2.62)	1.50 (0.76–2.96)	0.161
Adjusted[c] analysis					
Case status	1.0	NS	NS	NS	—
Asthma	1.0	1.56 (0.70–3.46)	2.05 (0.94–4.47)	2.93 (1.36–6.34)	—
Rhinitis	1.0	NS	NS	NS	—
Eczema	1.0	NS	NS	NS	—

—, no analyses have been done because linear-by-linear association cannot be done in a multivariate manner; NS, not significant in model, using backward elimination; ref, reference.
[a]Case status and subgroups with asthma, rhinitis, or eczema compared with controls. [b]Linear-by-linear association.
[c]Adjustments made for sex, age, smoking at home, type of building, construction period, self-reported flooding during preceding 3 years, and the other phthalate variable (in quartiles), using backward elimination method; only significant variables were included in the final model.
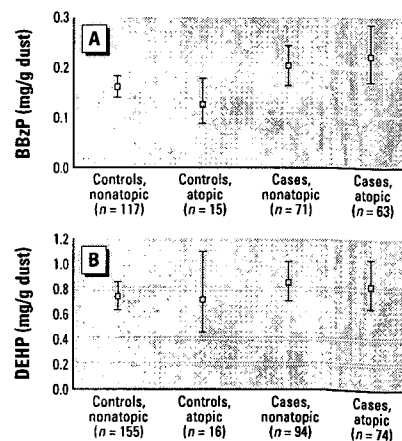

Figure 1. Geometric mean concentrations (95% CIs) of phthalates (A), BBzP, and (B), DEHP in surface dust from bedrooms of nonatopic and atopic children.

The reported analyses are based on samples with a weight > 25 mg. However, when including all samples ($n = 362$), the reported associations between exposure and symptoms remained or became stronger (data not shown).

Koo et al. (2002) present weak associations between exposure estimates for different phthalate esters, based on their urinary biomarkers, and the level of education, family income, and residency (urban or rural) in a reference U.S. population. Given that study, one might speculate that the associations reported in the present study are driven by demographic factors. However, in contrast to the United States, where 22.4% of the children live in households with incomes < 50% of the national median, in Sweden only 2.6% of the children live in such households (Unicef 2000). Additionally, the association in our study holds when the analysis is restricted to single-family houses; such homes have an even more homogeneous socioeconomic status. Hence, different demographic factors between cases and controls appear to be an unlikely explanation for the associations observed in the present study. Furthermore, given that the dust concentrations of DnBP, BBzP, and DEHP display quite different associations with different symptoms, the associations reflect a biologic response rather than just lifestyle or demographic factors associated with an increased use of plasticized materials.

This study demonstrates associations between BBzP and DEHP concentrations in dust and selected allergies and asthma. Although multiple factors likely are responsible for the increases in allergies and asthma that have been documented in developed countries over the past 30 years, it is striking that these increases have occurred during a period when plasticized products have become ubiquitous in the homes, schools, and workplaces of the developed world.

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